SYMPOSIUM
"WATER 2000" - "EAU 2000"

On the occasion of the 40th Anniversary of the International Water Supply Association.

A l'occasion du 40ième Anniversaire de l'Association Internationale des Distributions d'Eau.

PREPRINTS

ACTES PRELIMINAIRES

***

'ice (France) 8 - 11 SEPTEMBER / SEPTEMBRE 1987

WATER
EAU 2000

IWSA
AIDE
1947-1987

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WATER 2000 / EAU 2000

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Poster Presentations - Présentation d'Affiches

SEANCE D'OUVERTURE
OPENING SESSION

- Ressources en eau et environnement
  Water Resources and the Environment

  par / by J.B. GILBERT (E.U. - U.S.A.)

  (Résumé - Abstract).

- Recherche dans le domaine de l'eau
  Water Research

  par / by M.J. ROUSE (G.B.)

  (Résumé - Abstract).

- L'eau et la santé
  Water and Health

  par / by J. COTRUVO (E.U. - U.S.A.)

  (Résumé - Abstract).

WATER IN THE YEAR 2000 : WATER RESOURCES AND THE ENVIRONMENT

Jerome B. Gilbert, General Manager
East Bay Municipal Utility District, USA

ABSTRACT

The history of water management is occurring in cycles of action and reaction. Water development for people, industry, and farming is followed by recognition of the adverse impacts of that development. These two phases are universal, but are manifested differently in each locality. The pattern is repeated on a worldwide basis as populations grow and technology is applied to provide for a healthier and better life. The goal for the 21st Century should be to reach a third and more rational phase of long-term balanced water management.

California may be seen as a case history of the three phases. Approximately 80 % of the state's water supply originates in the north, and the majority of agricultural and urban demand is in the central and southern areas. This lopsided distribution led to an ambitious program of water resource development, which began in the late 19th Century and extended well into the mid-part of the 20th. In recent decades, there has been a strong reaction to the perceived impacts of California's rapid development. This reaction emphasizes dedication to preserving instream uses and natural wetlands and preventing any contamination from toxic chemicals. There are a growing number of national and state laws being implemented by a complicated and underfunded bureaucracy. The United States equivalent of the Green Party, with full media support, demands standards that are unqualified by economics.

The year 2000 will and should offer a new balance. There will be more rational and comprehensive laws and governmental actions. A major legal proceeding now underway in California could present an encouraging precedent for the future. The extraordinary public interest and concern about water can provide the basis for change. Important issues need to be addressed. They include : better ecological and water resources and quality data, minimizing rather than eliminating health risk, ensuring that water resource management professionals are properly informed, and upgrading and expanding technology exchange efforts. IWSA can play an important role in achieving a year 2000 in which more of the world's population will benefit from balanced water management.

IWSA SYMPOSIUM "WATER 2000" NICE, FRANCE,
KEYNOTE PAPER : WATER RESEARCH BY M J ROUSE

ABSTRACT

A perspective is created by comparing an average family's water needs in 1947 with its expectations today and likely aspirations in the next century. Instances are given of some of the technical achievements which have serviced these needs to date and of the research developments which have played an important role in stimulating advances in technology. Examples are drawn from controlling the coagulation process, managing waterworks sludge, chemical and microbiological analysis and water distribution.

The principal factors which have influenced these achievements and prompted change are considered in relation to the role that R&D has to play in helping to shape the future. A key strategy will be the integration of all the essential elements of water supply practice, including research, in order to improve standards and to meet customer expectations. The integrated approach will need to acknowledge a closer partnership between customer and supplier especially in the area of environmental management.

Health Aspects of Drinking Water Supplies in the 2000

Joseph A. Cotruvo
Director, Criteria and Standards Division
Environmental Protection Agency

We should assume that most of the water quality problems and questions that are being identified today will still exist in many communities in the year 2000, plus more that will be discovered as more sensitive analytical technology is applied to drinking water. Among the most acute current problems are : virus and protozoa in most surface and some ground waters; legionella in distribution systems; toxicity questions on disinfectants and their organic by products; corrosion and release of lead from pipes; solders and plumbing fixtures; volatile synthetic organic chemical contaminants in ground waters; pesticides in ground waters and surface waters; and radon in ground waters.

We should assume that more contaminants will be found because more sophisticated analytical methods will be used and more and better treatment technologies will be installed. More stringent national regulations will be developed to control operations and water quality, and the cost of water will surely increase.

Above all, even though most drinking water is unlikely to represent a significant risk, the public will demand more assurances of safety and quality from water suppliers. If those demands are not met, a loss of confidence in public water supplies will lead to a greater exodus to bottled water and point-of use treatment technology. The public will have less willingness to bear the cost of production of high quality drinking water by the public supplies.

The challenge to public water suppliers is to prevent that loss of confidence from occurring by taking the visible lead in protection of water sources from contamination and developing and applying those technologies that assure the highest quality of drinking water at the consumer's tap. In that way the quality and safety of drinking water would not be an issue for public concern.

SESSION 1

SEANCE 1

Chairman
Président K.F. ROBERTS

- Public Utility Networks in the 3rd Millenium

  Réseaux Publics de Distribution d'Eau du 3e Millénaire

  O. Halpern, O. Pascal

- Long-Term Requirements and Policies for Water Supply

  Impératifs et politiques à long terme de la distribution d'eau

  R. Herz, K. Hochstrate

Discussion

RESEAUX PUBLICS DE DISTRIBUTION D'EAU DU TROISIEME MILLENAIRE

Olivier HALPERN et Olivier PASCAL

Compagnie Générale des Eaux
52, rue d'Anjou - 75008 PARIS - FRANCE -

RESUME

Une prospective sur l'évolution des réseaux d'eau potable s'appuie sur :

- la nécessité d'une forte continuité avec le passé, pour des ouvrages à grande longévité,
- la prise en compte des innovations technologiques dans le domaine des matériaux, de la robotique, des capteurs, de l'informatique,
- la prise en compte renouvelée de problématiques comme l'encombrement du sous-sol, la garantie de la qualité de l'eau, la gestion intégrée d'ouvrages complexes.

MOTS-CLES

CAO ; capteurs ; cartographie ; céramiques ; encombrement du sous-sol ; garantie de la qualité du service ; informatique ; innovation ; investissements de rationalisation ; matériaux composites ; matériaux de synthèse ; programme Eurêka ; réseau d'eau potable ; résines époxy ; robotique ; système-expert ; troisième millénaire

INTRODUCTION

Les réseaux publics de distribution d'eau sont le plus souvent constitués d'ouvrages de grande longévité. On peut même dire que le recours aux technologies les plus durables est une tradition qui ne s'est jamais démentie depuis les origines, très anciennes, du service de l'eau.

La raison principale en est, sans nul doute, que l'eau a été considérée, en tous temps et en tous lieux comme un bien vital. Ainsi, on s'est préoccupé très tôt de sélectionner les technologies les plus adaptées à son transfert et à sa distribution. Les anciens Romains, à défaut d'être les seuls, sont probablement le peuple qui s'est le plus illustré dans l'avancée des techniques hydrauliques. De nos jours et du fait du perfectionnement précoce des techniques de distribution, le service public de l'eau peut être assuré, dans le contexte économique des pays développés, à un coût relativement bas. La modicité des prix pratiqués a elle-même amené les gestionnaires de réseaux à utiliser le plus longuement possible les lourdes immobilisations capitalistiques que représentent les réseaux enterrés et à continuer à sélectionner les technologies les plus durables.

L'évolution des réseaux de distribution d'eau, à l'approche de l'an 2000, doit alors tenir compte de ce facteur essentiel : les nouvelles techniques de distribution, quel que soit leur objet, doivent être compatibles avec des systèmes d'ensemble souvent fort anciens, le plus souvent de qualité, dont l'adaptation sera progressive et marginale. Cela ne veut pas dire, et cet exposé en donnera quelques éléments, que ces adaptations ne seront pas substantielles. Mais cela veut dire que les développements continueront probablement à se faire en mariant harmonieusement les techniques de demain avec celles d'aujourd'hui, de même que se marient, dès maintenant, les techniques d'aujourd'hui avec celles d'hier [figure 1].

D'une manière générale, cette coexistence des techniques et des méthodes nouvelles pour concevoir et gérer les réseaux d'eau potable, avec des techniques plus anciennes, doit perpétuer le principe d'ouvrages d'ensemble de grande longévité, au-delà de la centaine d'années, et ainsi couvrir une portion notable du nouveau millénaire.

I - LES NOUVELLES TECHNOLOGIES

La fin du XXe siècle voit, dans de multiples domaines, se maintenir un rythme d'innovation technologique extraordinaire, que ne ralentissent apparemment même pas les crises qui secouent les économies occidentales. C'est peut-être même une intuition contraire qu'a traduit, il y a quelques années, le slogan français : "on n'a pas de pétrole, mais on a des idées".

Quoi qu'il en soit, ce sont dans des domaines industriels fort éloignés de la distribution d'eau, et qu'ont irrigué des efforts financiers de recherche et développement considérables, que sont apparues les innovations technologiques qui, peu à peu, au prix d'adaptations prudentes et systématiques, se tranfèrent maintenant au monde des réseaux d'eau potable.

Quelques champs technologiques sont particulièrement intéressants à ce titre.

Les matériaux nouveaux

Les matériaux nouveaux comprennent soit des produits de synthèse chimique, soit des matériaux composites, conçus de manière à atteindre des objectifs qui, il y a peu, paraissaient contradictoires : robustesse et légèreté, inertie chimique et facilité de fabrication et réparation.

Les industries aéronautiques et chimiques ont ainsi suscité des innovations qui s'avèrent très prometteuses.

L'exemple le plus évident est celui des matières plastiques. Depuis une vingtaine d'années leur emploi s'est étendu aux canalisations de petits diamètres (PVC), aux branchements (polyéthylène), aux diamètres intermédiaires (tuyaux composites en PVC fretté de fibre de verre jusqu'à 400 mm [figure 2]). L'utilisation de ce type de tuyaux devrait continuer à se répandre car leurs avantages sont nombreux (légèreté, résistance aux sols et aux eaux corrosifs) et leurs limitations d'emploi éventuelles de mieux en mieux cernées et supprimées (porosité, stabilité chimique, résistance aux hautes pressions). On peut même imaginer que des matériaux de synthèse, où interviennent les fibres de carbone, le kevlar donneront un jour naissance à des tuyaux qui cumuleront toutes les qualités ci-dessus énumérées et la faculté de procéder à des réparations ou modifications de forme sur le chantier, source de gain de temps et d'efficacité.

Les matériaux de synthèse apportent également dès aujoud'hui leur contribution aux perfectionnement des ouvrages accessoires de réseau : on résout ainsi le vieux problème des regards antigels avec des coffrets aisés à réaliser et à standardiser [figure 3], on dote les robinets-vannes de joints étanches et durables. Demain, les opercules de vanne, les actionneurs, les différents organes hydrauliques utiliseront des matériaux de synthèse, comme les céramiques, et se soustrairont définitivement aux problèmes de la corrosion.

Les canalisations en fonte et en béton armé, qui bénéficient d'un concept technique très au point, particulièrement convaincant sur le thème important de la durabilité, amélioreront encore leurs performances en affinant les possibilités qu'offre leur conception composite. Ainsi, pour résister à la corrosion extérieure, certains fabricants de tuyaux en fonte revêtent déjà leurs produits de résines époxy très résistantes. Les fabricants de tuyaux en béton armé bénéficient déjà d'une extrême régularité de qualité dans la production grâce à des chaînes de production très automatisées et emploient les matériaux de synthèse pour traiter des points particuliers comme les joints isolants [figure 4], les tés de décharge ou de ventousage [figure 5]. D'une manière générale, l'incorporation judicieuse de matériaux de synthèse continuera à permettre un enrichissement des performances des produits actuels, issus de concepts technologiques éprouvés.

Enfin, en laissant aller son imagination, on prévoit la généralisation des produits thermodurcissables qui permettent la réparation d'ouvrages anciens, dans de bonnes conditions de solidité, de gaines en matériaux de synthèse qui permettent le tubage plastique des canalisations usagées, de mousses expansibles pour des consolidations diverses, etc.

La robotique

On ne s'étend pas ici sur l'automatisation des usines qui produisent les matériels utilisés pour la distribution d'eau ; rappelons simplement que cette automatisation a des effets souvent très positifs sur la qualité des produits.

Les robots sont apparus dans le domaine des industries nucléaires, océanographiques ou spatiales, pour aider à la réalisation de travaux dans des ambiances difficiles [figure 6]. Puis leur utilisation a commencé à se banaliser, par exemple pour le nettoyage d'installations délicates (métro de Paris, réservoirs d'eau potable).

Dans le domaine de la pose des canalisations, les robots constituent souvent encore une vision d'avenir, mais les problèmes d'encombrement du sous-sol les rendront nécessaires. Dans l'immédiat, les prémisses de la robotisation sont visibles dans la mécanisation élaborée des techniques de terrassement et de pose des canalisations [figure 7].

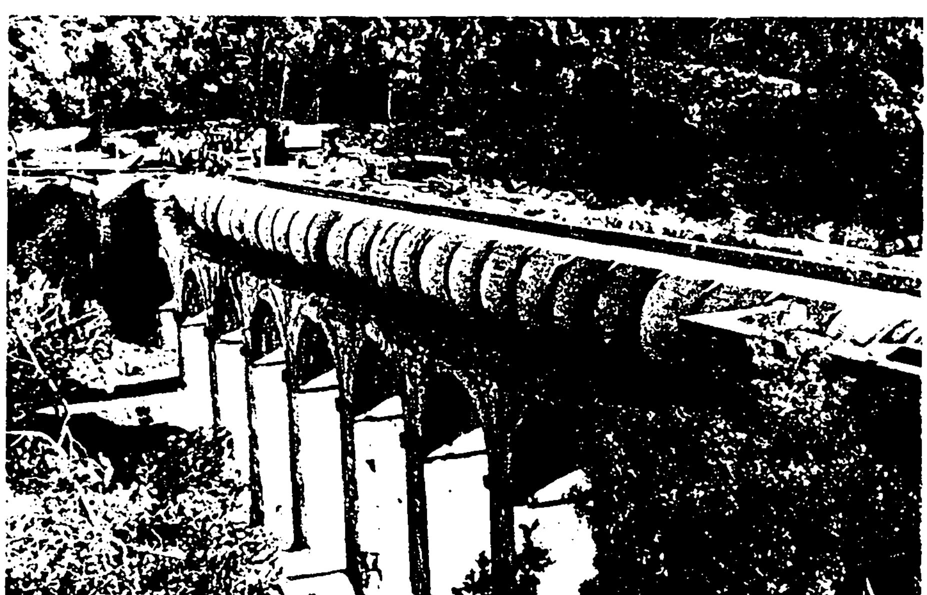


Fig. 1. Restauration d'un pont-aqueduc du canal de Marseille
avec une canalisation en béton armé (Doc. Bonna)

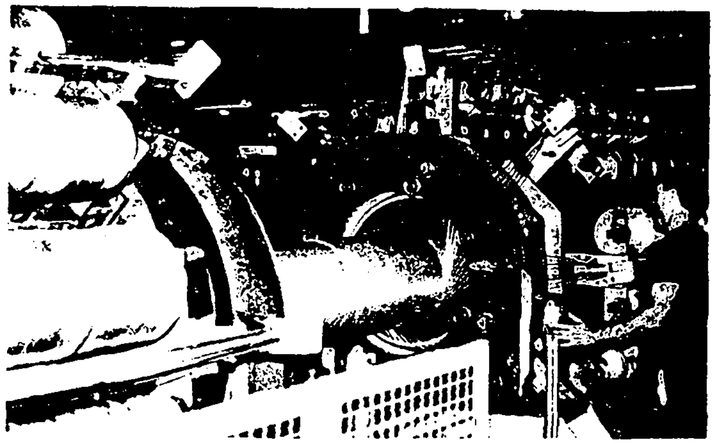


Fig. 2. Chaîne de fabrication de tuyaux en matériaux composites
(Doc. Seperef)

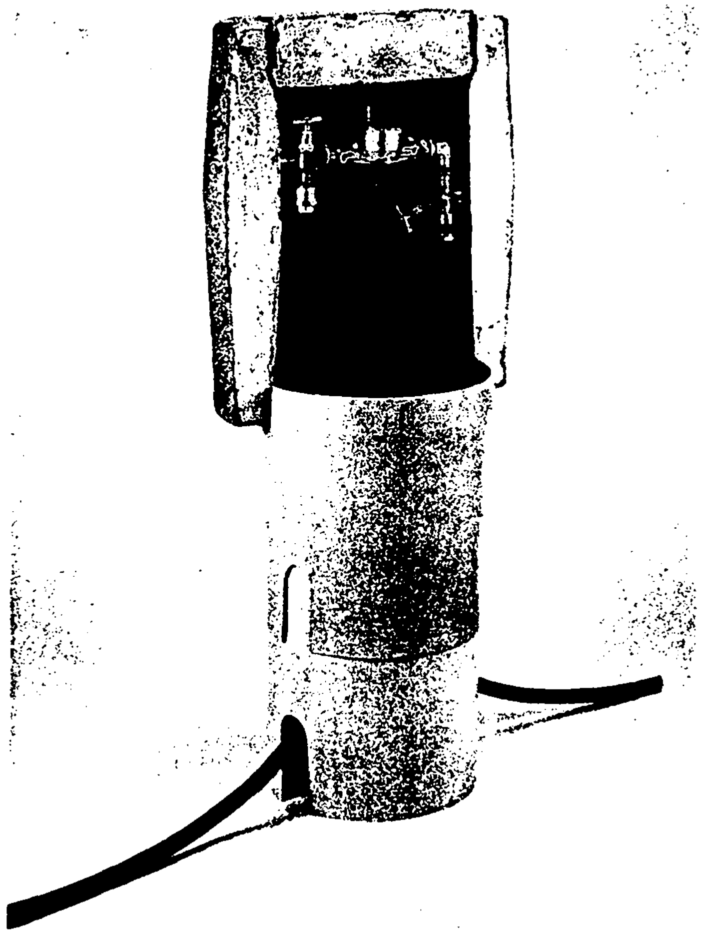


Fig. 3. Coffret de comptage antigel en matériaux de synthèse
(Doc. Seperef)

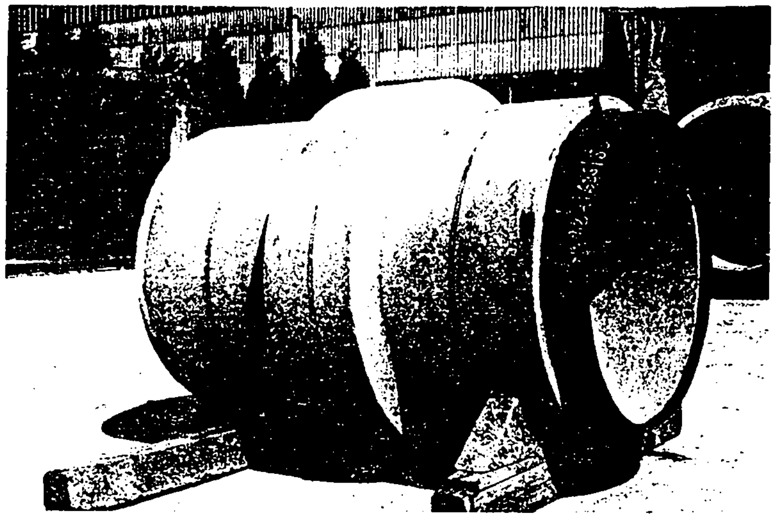


Fig. 4. Joint isolant standardisé pour canalisations en béton armé
(Doc. Bonna)

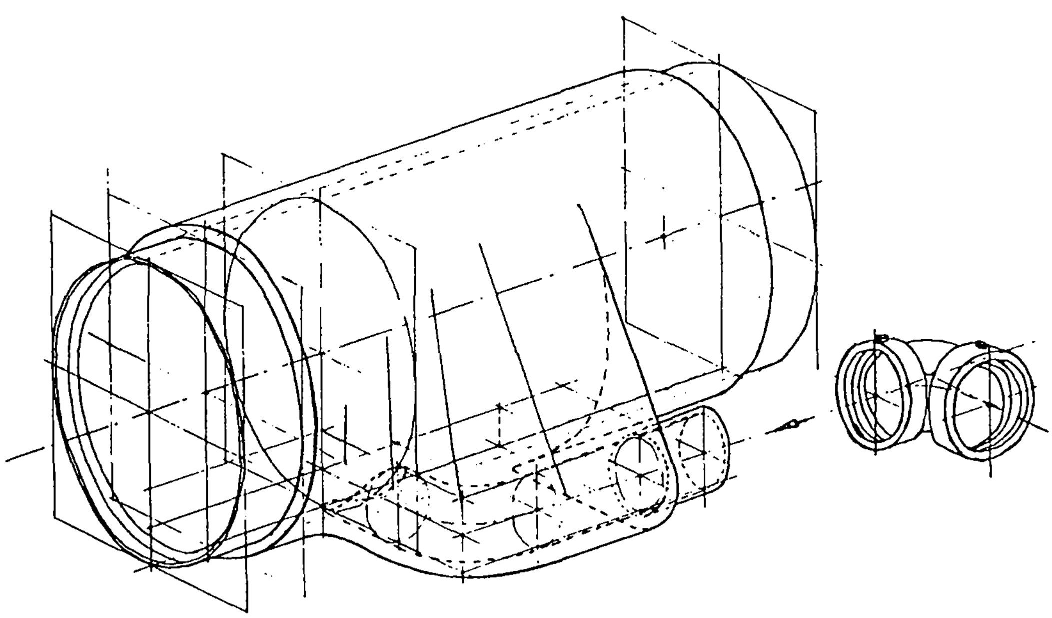


Fig. 5. Pièce spéciale de canalisation composite associant une tubulure en polyethylène
et un tuyau en béton armé (Doc. Cie Gle des Eaux)

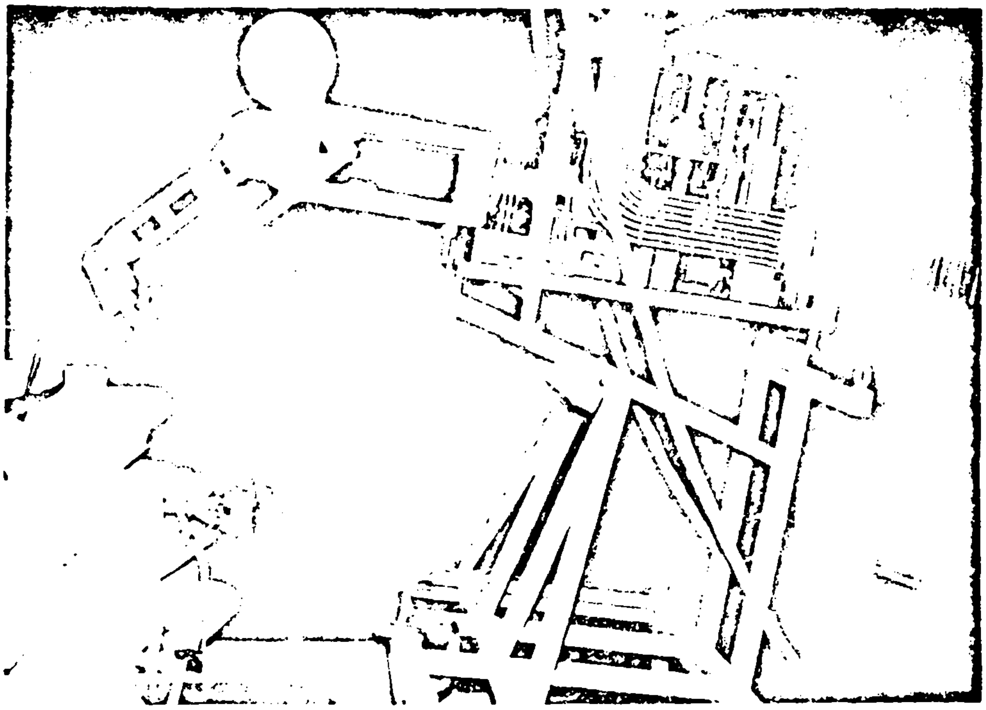


Fig. 6. L'industrie nucléaire a été l'initiateur dynamique de la création de robots pour des manipulations en environnement hostile (Doc. CEA)

Fig. 7. La pose de canalisations implique de plus en plus l'usage de machines sophistiquées prémonitrices de robots adaptés à cet usage

Dans le domaine de l'entretien des canalisations, les techniques robotiques s'appliquent déjà, qu'il s'agisse de les inspecter, de les nettoyer, de procéder à leur réfection.

L'inspection des canalisations peut concerner leur état d'encrassement ou de corrosion et dans les canalisations de gros diamètres, on fait déjà évoluer des caméras [figure 8].

Les cas difficiles de nettoyage sont le plus souvent résolus par le passage de bouchons-racleurs (pigs) de caractéristiques variées, adaptées aux types d'intervention qui sont nécessaires. Cette adaptation va jusqu'à l'emploi, dans des cas particuliers, de véritables robots, par exemple pour lancer des jets d'eau giratoires, sous très haute pression.

Gageons que ces techniques continueront à se perfectionner, dans la perspective de prolonger l'[illegible] des canalisations existantes.

Dans cette même idée, en cette fin de XXe siècle, on voit émerger des techniques très automatisées de réfection de canalisations usées, par des tubages métalliques, des revêtements intérieurs de ciment, des films époxy ou thermoplastiques. Ces revêtements ainsi reconstitués sont mis en oeuvre par des techniques très automatisées, proches de la robotisation, comme par exemple le tubolining pour les revêtements au mortier de ciment [figure 9].

Les capteurs

Les derniers développements de la physique appliquée commencent à trouver leur application dans la conception et l'exploitation des réseaux d'eau potable.

On peut citer quelques innovations, dont certaines ne manqueront pas d'avoir des suites marquantes.

L'utilisation banalisée des rayons laser s'applique aux chantiers de canalisation pour marquer les alignements, par exemple dans les opérations de fonçage.

L'analyse de la réflexion des ondes électromagnétiques [figure 10] (principe du radar) permet le repérage des canalisations enterrées, qu'elles soient métalliques ou non, et constituent un outil intéressant pour la reprise des réseaux anciens.

Les capteurs de champ magnétique, couplés à des systèmes d'induction, sont à la base des robots conçus pour rechercher, de l'intérieur des canalisations en acier, ou en fonte, les parties corrodées.

Un champ très prometteur d'emploi des capteurs est celui des analyseurs physico-chimiques [figure 11] qui permettent de connaître, en continu ou par des méthodes de terrain, rapides et légères, la qualité de l'eau distribuée. De tels analyseurs ont connu un premier développement spectaculaire dans le domaine de la surveillance du milieu naturel et du suivi des filières de traitement. Il est à prévoir que leur emploi va se renforcer pour le suivi de la qualité de l'eau en réseau.

Enfin, les capteurs physiques classiques, qui mesurent la pression, les niveaux, les débits, continueront à bénéficier d'améliorations qui permettront une maintenance réduite et effectuée selon des procédures standardisées. A cet effet, ils emploient les effets physiques les plus élaborés. Imaginons le laser pour les niveaux, l'effet doppler pour les débits.

L'informatique

Les évolutions des technologies de l'information ont trouvé très rapidement des applications pour la conception et la gestion des réseaux d'eau potable. Il serait téméraire de chercher à prédire quelles seront les évolutions complémentaires que connaîtra l'informatique, tant son passé récent a été rapidement bouleversé. On peut simplement, sans risque d'erreur, affirmer qu'un proche futur (disons les vingt prochaines années, jusqu'à l'aube du XXIe siècle) verront se compléter et se généraliser la mise en place d'un certain nombre de systèmes de traitement automatique de l'information appliqués aux réseaux d'eau potable.

Cette généralisation comprendra les éléments suivants :

- Les informations multiples collectables sur un réseau, issues des analyseurs de qualité d'eau, des capteurs physiques sur les débits, pression, niveaux de réservoir, etc, seront la base d'automatismes locaux très sophistiqués pour la gestion des pompages en réseau, des chlorations en réseau, des régulations de pression limitant les fuites, d'automatismes assurant le renouvellement de l'eau dans les feeders utilisés de manière intermittente.

  Les techniques de la microinformatique, adaptées à l'environnement industriel permettront de telles fonctions, avec des modes de maintenance aisés à assurer.

  La microinformatique utilisée localement ne prendra toute sa valeur que dans un système global de répartition de l'informatique, avec des modes de télétransmission adaptés, conçus pour faciliter la gestion en temps réel des réseaux.

- Les capacités mémoire importantes des unités informatiques modernes, avec les logiciels de gestion de bases de données qui en permettent une utilisation facile, sont de plus en plus utiles pour l'archivage, la consultation, le suivi des très nombreuses données techniques et administratives qui décrivent l'état d'un réseau [figure 12].

- Les techniques de restitution graphique, dite infographique, ont également un bel avenir dans la profession :

  . il s'agit de la cartographie pour l'ensemble des plans du réseau.

  . il s'agit de la CAO pour l'élaboration des plans de projet, associée à des moyens bureautiques puissants au bureau d'études [figure 13].

  . il s'agit des synoptiques animés, pour les salles de commandes d'exploitation [figure 14].

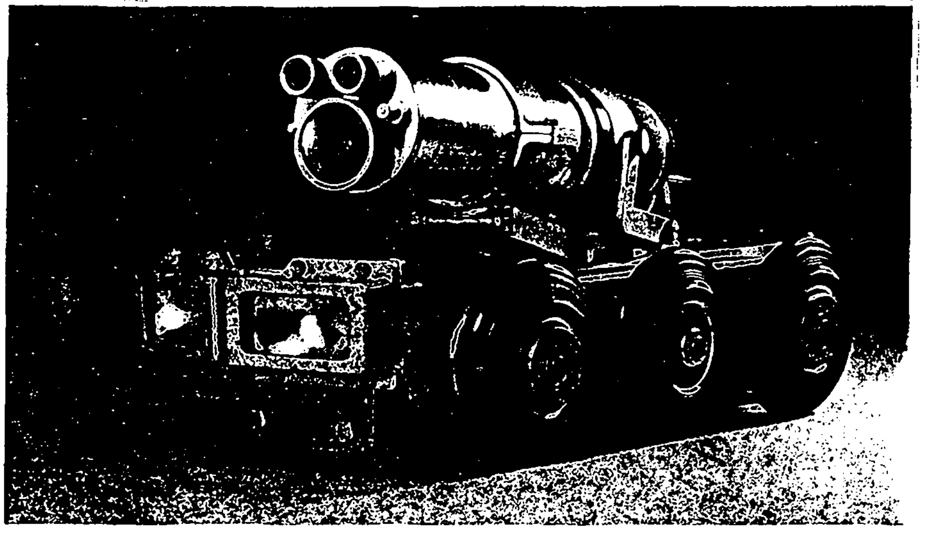


Fig. 8. Caméra robotisée pour inspecter les canalisations de grand diamètre

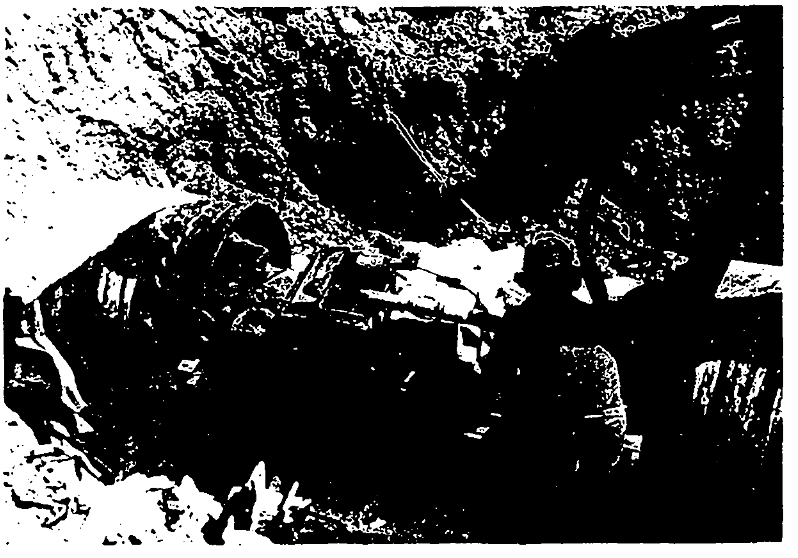


Fig. 9. Machine robotisée pour mise en place de revêtement en mortier de ciment

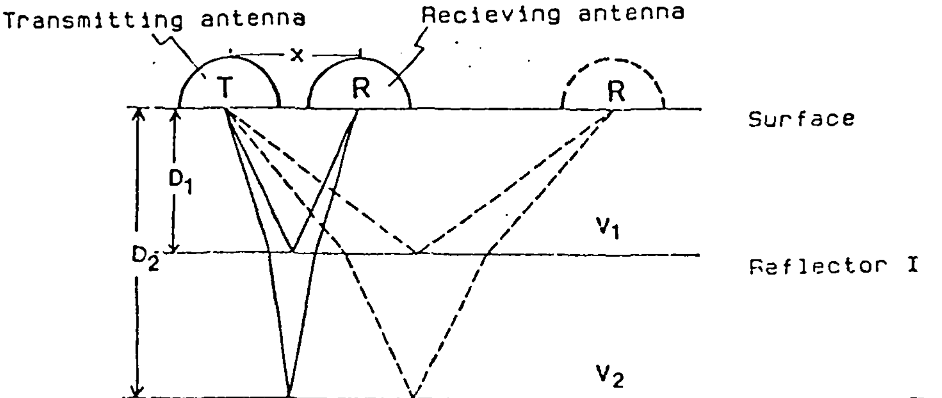


Fig. 10. Location de canalisations enterrées par radar

Fig. 11. Batterie d'analyseurs automatiques de qualité d'eau
(Doc. SEIT)

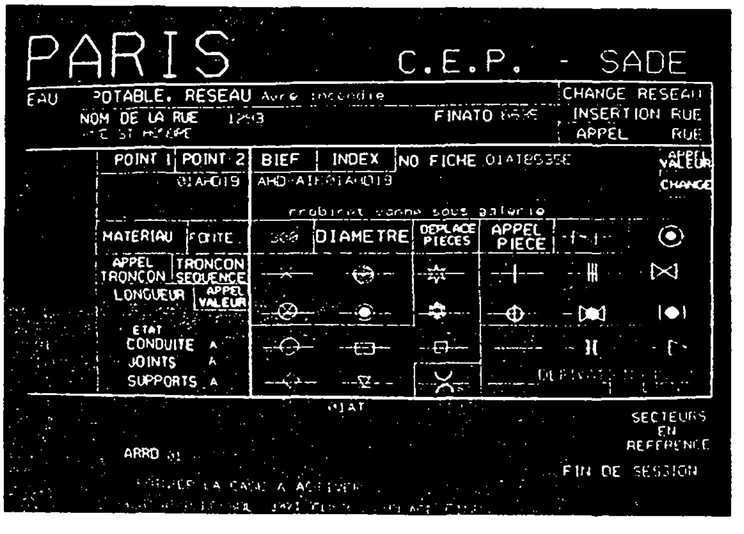


Fig. 12. La Compagnie des Eaux de Paris dispose d'une base de données informatisée très complète des caractéristiques de son réseau (Doc. Sade)

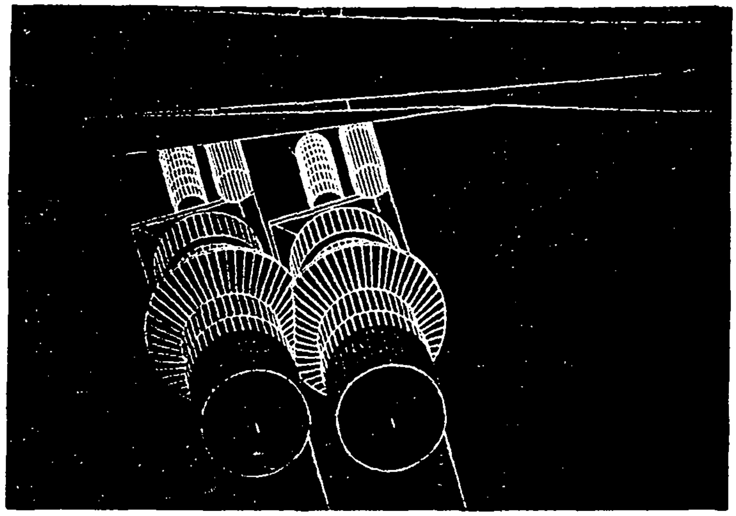


Fig. 13. La Conception Assistée par Ordinateur permet des gains de productivité au niveau du bureau d'études, mais surtout, révolutionne l'organisation des fonctions de conception (Doc. Campenon Bernard)

Fig. 14. Un logiciel de restitution graphique permet la visualisation à l'écran, en temps réel, des principaux états hydrauliques d'un réseau de distribution (Doc. Sade)

Au-delà de ces généralisations de l'emploi de l'informatique, certains esprits imaginent, et c'est le domaine de la "conception généralisée" déjà opérationnelle dans des secteurs comme l'aéronautique ou l'armement, que les gains de productivité et de fiabilité apportés par les techniques informatiques seront tels qu'ils influent profondément la conception même des organisations auxquelles elles s'appliquent. Et cela est tout à fait vraisemblable en ce qui concerne l'organisation des bureaux d'études qui se dotent de la CAO, ou des systèmes de télétransmission qui seront allégés dès lors que les capteurs et actionneurs locaux seront complétés par des microprocesseurs industriels locaux, avec d'importantes capacités mémoire et des automatismes sophistiqués. Parallèlement, les ordinateurs centraux, chargés de superviser la gestion courante des réseaux, assureront des fonctions de gestion plus générales, seront dépouillés des fonctions assurées par les automatismes locaux, et seront conçus pour présenter de la façon la plus synthétique les données propres à la gestion du réseau. Dotés de logiciels de restitution graphique et de systèmes experts permettant de sélectionner les configurations d'exploitation suivant une combinaison de critères quantitatifs et qualitatifs, il décaleront la fonction de gestionnaire de réseau de celle d'un homme-orchestre, limité dans ses possibilités harmoniques, à celle d'un véritable chef d'orchestre.

2 - LES NOUVELLES PROBLEMATIQUES

L'insertion de ces nouvelles techniques dans le domaine de la distribution d'eau peut être envisagée avec plus de précision si on se réfère aux principales problématiques auxquelles ce domaine est confronté, au crépuscule du XXe siècle, et qui seront probablement toujours importantes en l'an 2000.

L'encombrement du sous-sol des grandes cités est une donnée de plus en plus primordiale. La concentration urbaine, et surtout la multiplicité des relations qui s'établissent au sein de la ville, font que les réseaux de toute nature se développent sans relâche.

Le premier défi est donc la connaissance du sous-sol encombré, et les techniques informatiques évoquées plus haut, qui débouchent sur des bases de données cartographiques, doivent permettre de généraliser les plans urbains très détaillés sur l'utilisation du sous-sol.

Ensuite, il faut envisager la mise en place de réseaux multicanaux, qui intègrent les fluides techniques (eau, gaz, chauffage urbain, électricité) et le transfert d'informations (câbles optiques ou coaxiaux, paires téléphoniques). Ces réseaux multicanaux seront d'abord des réseaux individualisés posés dans le cadre de chantiers communs et on peut envisager des instituts multiservices qui se chargent de la programmation de tels développements.

Ces développements peuvent s'appuyer sur des outils particuliers comme des systèmes multicanaux standardisés. Un exemple très illustratif est celui du projet "Infrastructures Urbaines Industrialisables" [figure 15], mis en oeuvre par une équipe d'entrepreneurs européens, dans le cadre du programme EUREKA.

D'autres complémentarités pourraient être dégagées, par exemple en posant des câbles optiques dans les canalisations d'eau, etc.

Enfin, le problème de l'encombrement du sous-sol débouchera sur le perfectionnement des techniques de chantier fondées sur l'automatisation et la robotisation évoquées plus haut.

La garantie de la qualité de l'eau est un impératif qui se présente en termes renouvelés par rapport à ce qu'on concevait il y a quelques années. Les facteurs de cette évolution sont les suivants :

- d'une part, les progrès des méthodes analytiques [figure 16] ont permis au laboratoire de contrôler de nombreux paramètres représentatifs de la qualité de l'eau. Les normes s'inspirent de ces progrès, puisque les directives européennes de 1980, en matière d'eau de consommation, considèrent 63 paramètres.

- d'autre part, en relation avec le point précédent, et du fait de la dégradation du milieu naturel, les usines de production d'eau potable, à partir d'eau souterraine ou superficielle, ont dû se perfectionner, avec des progrès techniques souvent remarquables. Mais les augmentations de coût de production ont souvent été importantes.

Ces efforts à l'origine ont fait apparaître sous un jour accentué la nécessité de ne pas laisser la qualité de l'eau se détériorer ensuite dans le réseau de transport et de distribution.

De cet impératif de maintien d'une qualité chèrement obtenue, résulte la mise en place de politiques en matière de distribution d'eau :

- on cherche à produire une eau "stable", c'est-à-dire dépourvue de ces composés organiques qui, même à l'état de trace, peuvent induire des proliférations bactériennes, des saveurs par réaction avec les produits de désinfection chlorés, des réactions plus ou moins nocives avec les parois des canalisations. Cet objectif de "stabilité" se détermine par une approche analytique très recherchée, de jour en jour perfectionnée par des biochimistes de l'environnement [figure 17].

- on sélectionne des matériaux pour réaliser les canalisations qui possèdent une inertie biochimique en rapport avec l'objectif précédent.

- on mesure, en des points cruciaux du réseau, de plus en plus souvent en continu, la paramètres significatifs de la qualité de l'eau.

- on organise les mouvements d'eau en général d'une manière à minimiser les temps de séjour et les zones d'eau morte. Cela implique un contrôle et des automatismes de conduite du réseau très élaborés pour les réseaux maillés, conçus pour assurer la sécurité la meilleure.

On retrouve ici l'utilité des nouvelles techniques informatiques, évoquées plus haut.

La garantie de la permanence du service se pose dans des termes difficiles pour les grandes agglomérations dont les réseaux de distribution d'eau représentent des ouvrages complexes et sophistiqués.

La conduite de grands réseaux urbains s'aborde alors en termes de hiérarchisation des objectifs. Pour le simple aspect hydraulique des choses, on s'efforce de distinguer le fonctionnement de sous-réseaux locaux des grands mouvements d'eau que permettent les différentes adductions, les intercommunications d'échange, etc...

Mais cette distinction théorique est souvent rendue malaisée par l'interpénétration des fonctions qu'assurent les ouvrages des réseaux anciens, qui se sont développés de façon très intégrée, selon des logiques aujourd'hui obsolètes.

Pour ce type de situation, il faut envisager des investissements de rationalisation qui permettent la mobilisation effective des grandes fonctions citées ci-dessus. Ces investissements comportent deux types d'ouvrages essentiels : des conduites de transport importantes permettant les grands échanges d'eau ; des stations de répartition des flux très automatisées et autonomes, incluant les fonctions de pompage, détente, mesures diverses, travaillant sous la supervision des centres de commande intégrés, dotés grâce à l'informatique de puissantes possibilités d'analyse, et de répartition des décisions.

Les évolutions en cours au service d'eau de Londres (Thames Water Authority) et à celui de la Banlieue de Paris (Syndicat des Eaux d'Ile de France, avec le concours de la Compagnie Générale des Eaux) sont éloquentes à cet égard [figure 18].

La permanence du service envisage aussi l'utilisation accrue des techniques d'analyse de la fiabilité par la sélection des investissements de sécurité et par la mise en oeuvre de protections particulières pour les points sensibles du réseau [figure 19].

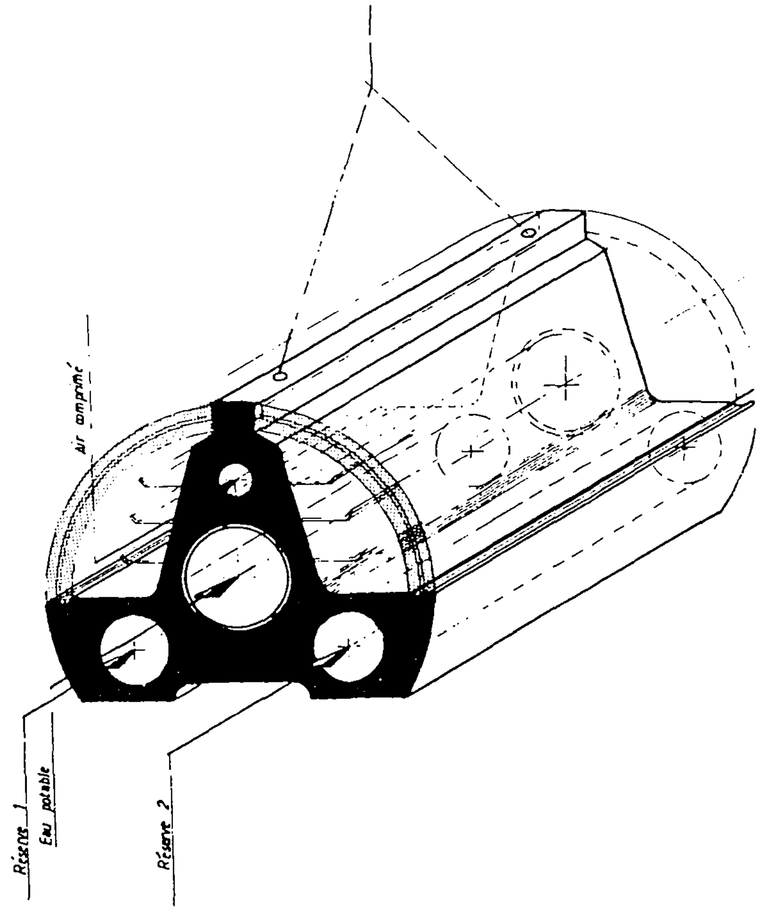


Fig. 15. Projet d'élément standard pour réseaux multicanaux - Système IUI du programme EUREKA (Doc. Bonna)

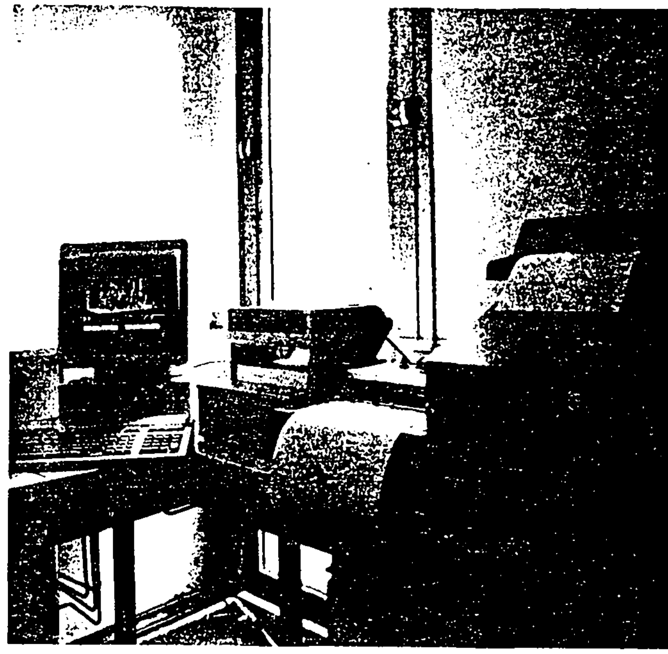


Fig. 16. Chromatographe en phase liquide tri-dimensionnel
(Doc. Anjou-Recherche)

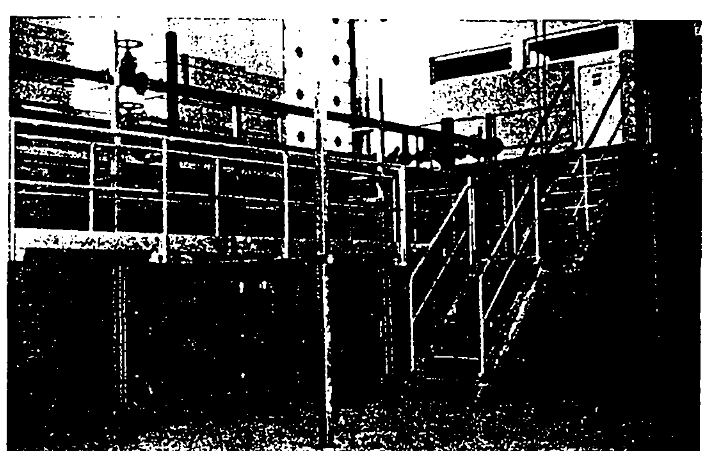


Fig. 17. Pilote de simulation de phénomènes biochimiques en réseau
(Doc. Centre International de l'Eau de Nancy)

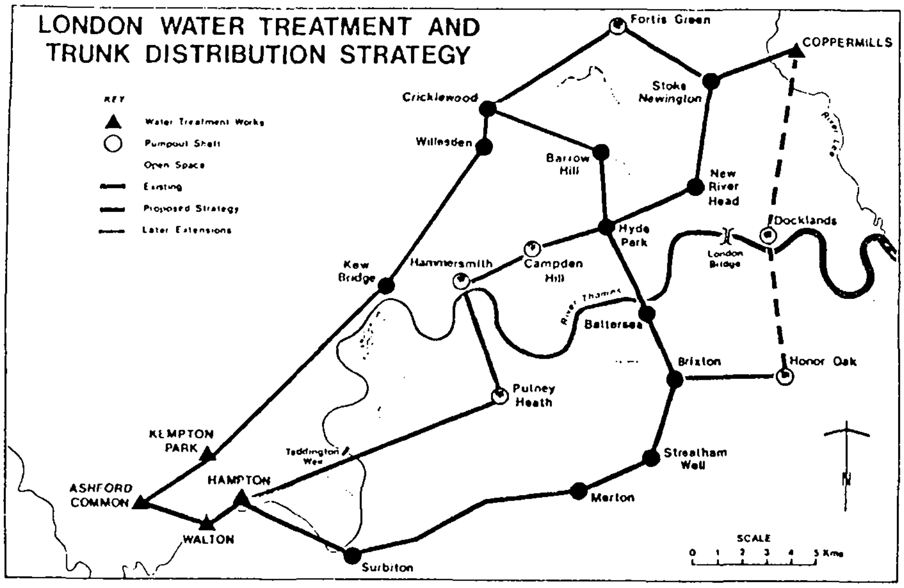


Fig. 18. A l'exemple de ceux de Paris et de Londres, les réseaux de distribution d'eau des grandes agglomérations urbaines seront hiérarchisés et rationalisés avec de grandes canalisations principales et une gestion centrale informatisée (Doc Thames Water Authority)

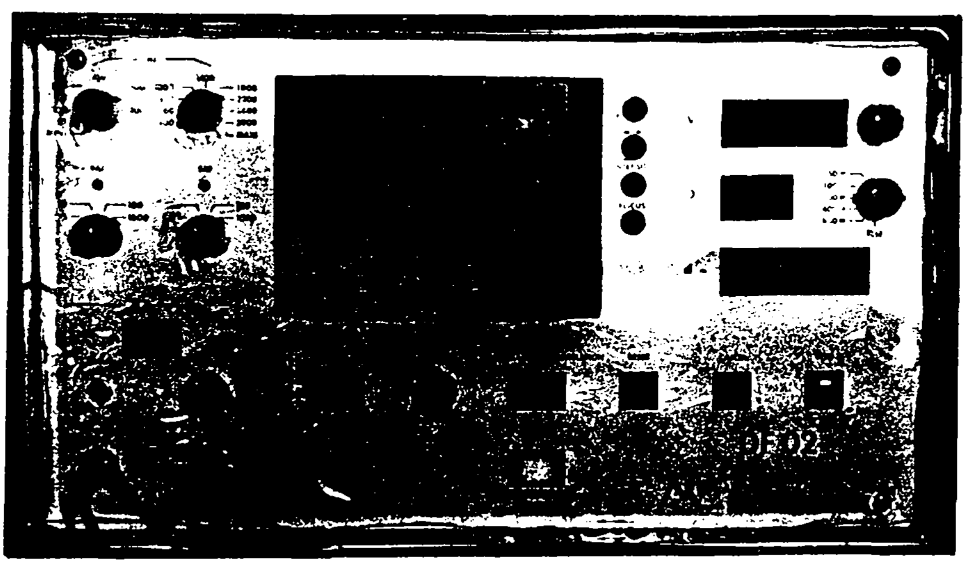


Fig. 19. Corrélateur acoustique fixe permettant de vérifier l'absence de fuite sur les points à risques

CONCLUSION

La juxtaposition de ces nouvelles problématiques, dont l'abord présente souvent des enjeux difficiles, et des multiples possibilités qui offrent de plus en plus des outils techniques très perfectionnés laisse penser que, dans les années 2000, la technicité des métiers de conception et d'exploitation de réseau va s'accroître.

C'est tout à fait probable, mais on peut imaginer que cette technicité n'apparaîtra pas comme telle car les nouvelles technologies des nouveaux matériaux aisés à travailler aux systèmes-experts, se caractérisent souvent par une grande facilité d'utilisation.

Le défi qui est donc posé aux responsables qui sont déjà chargés de la mise en place des réseaux d'eau de demain, est celui de l'inventivité et de la créativité pour l'utilisation la plus judicieuse des outils que la technique moderne met à leur disposition.

En effet, les métiers autour des réseaux d'eau ont été jusqu'à récemment marqués par l'utilisation des techniques très éprouvées, dont le succès était assuré par un état d'esprit rigoureux et méthodique chez ceux qui ont été responsables de leur emploi. Aujourd'hui et demain, sans se départir de cet état d'esprit, il importe particulièrement d'être attentif au fait que les enjeux de la distribution d'eau se renouvellent et se complètent dans des domaines inattendus. Les réponses viennent de domaines non moins inattendus.

Il en résulte cette nécessité d'innovation et de création, à conjuguer avec la rigueur habituelle pour un service public aussi fondamental. Le gestionnaire de réseau d'eau doit probablement d'abord se préoccuper de mettre en place les équipes humaines animées de telles convictions. Cette préoccupation s'inscrit dans des impératifs très concrets :

- une formation des personnels effectivement adaptée aux nouvelles méthodes des métiers de réseau ; ceci dès le recrutement et ensuite par une politique de formation permanente,

- une gestion du personnel dynamique, fondée sur le principe de petites équipes, autonomes, mobiles, avec un renouvellement fréquent des affectations, tous éléments propres à assurer la permanence de l'esprit d'initiative.

LONG-TERM REQUIREMENTS AND POLICIES FOR WATER SUPPLY NETWORK RENEWAL

R. Herz and K. Hochstrate
Institute of Urban and Regional Planning, Karlsruhe University,
Karlsruhe, Federal Republic of Germany

ABSTRACT

Past periods of network expansion in addition to different technologies applied to the water distribution network, have resulted and will result in a considerable variation of renewal investments over time. Long-term requirements and policies for water supply network renewal are discussed in this paper and presented in the form of a model, simulating network deterioration and renewal, which helps to identify an acceptable network renewal strategy with respect to the impacts on system performance and the utility company's investment and financial liquidity.

KEYWORDS

Water supply network; ageing; deterioration; renewal; pipe cohort survival; timing of pipe replacement and rehabilitation; interactive development of network renewal strategies; reliability; financial liquidity.

INTRODUCTION

Public utilities are spending large amounts of money on maintenance, renewal and expansion of water supply networks which represent about 80 percent of the total water supply system's assets. Management decisions relating to network renewal have considerable long-term effects on operational costs and service reliability. Thus, for efficient policy making, long-range forecasts are required not only for the most probable renewal demand, but also for the impact different renewal strategies might have on network condition and reliability, on maintenance and repair costs as well as on network depreciation and tariff policy.

The utility company's budgets and expenditures heavily depend on the existing stock and on the policies practiced in the past. They are gradually adjusted, from time to time, according to observed needs and trends. This procedure appears to be quite adequate in cases where the age and material structure of the network is relatively uniform. In reality, however, due to various periods of rapid expansion and to different technologies applied in the past, the elements of water supply networks are quite heterogeneous and have different life expectations. The future demand for network renewal will therefore vary to a large extent and cannot be forecast by conventional methods of trend extrapolation (Kottmann, 1978).

Long-term requirements for water supply network renewal are strongly influenced by not only measures taken in the past, but also in the future. Investments into network renewal depend on available funds and construction capacities. Accordingly, adjustments can be made by deciding on

- the time of renewal and the intensity of renewal at any time,
- the alternatives of replacing or rehabilitating parts of the network, and on
- the material used with respect to cost and durability.

These decisions will have consequences on system reliability, OMR costs and future investments. Public utilities would like to minimize their discounted renewal costs, but up to now the impacts of renewal decisions on the future system's reliability and repair costs and on the company's liquidity have been at best considered only in qualitative terms. It is here that the model presented in this paper attempts to make some contribution.

FACTORS INFLUENCING NETWORK RENEWAL

The renewal of water supply networks should not be just compensating for deficiencies which result from material deterioration, e.g. corrosion, incrustations and breaks, and from quantitative and qualitative functional inadequacies e.g. capacity bottlenecks and rising standards of water supply. The demand for network renewal might also be determined by goals for urban development in specific urban renewal areas, where new and more intensive land uses are envisaged, requiring a higher standard of water supply (Köhl/Herz, 1987). Furthermore, parts of the network are renewed when other public works are conducted in the same street section, such as a redesign or repavement of the street or a replacement of old sewers, gas or heating conduits. After all, the amount of money put into network renewal also depends on the intensity of maintenance and on the timing and technology of renewal measures.

Network Age and Materials

There are water-pipes and mains in town centres which date back to the last century. Theoretically, their life expectations ought to be already exhausted, and indeed, many of those first-laid pipes have been replaced by now for various reasons: frequent breaks, heavy incrustations, corrosion, insufficient capacity or, in the case of leaden pipes, for health reasons. Without inspection, it is difficult to say how long these very old conduits will last. However, experienced water works personnel would be able to estimate how old, on an average, a water pipe of a given material and diameter, built during a specific period, would probably last. They would take into consideration local factors, such as water hardness and subsoil aggressiveness, and they would know how well anti-corrosive insulation works on pipes of steel or malleable cast iron laid during specific years. Of course these are only estimates, but they could be intelligently included into a method to determine the demand for network renewal. Better forecasts of a pipe's lifetime can be made by systematically analysing inspection data, such as coefficients of roughness, or failures, such as frequency of breaks or major leakages (O'Day, 1983). However, up to now most utility companies have only rudimentary information systems on network condition.

Standards for Network Condition

Water-pipes and mains, after working perfectly for years, tend to drift slowly into a state of deterioration which calls for renewal activities. It is up to the company to decide what degree of malfunctioning and what frequency of failures will be acceptable. Shamir and Howard (1979) have suggested replacement of a pipe when the discounted accumulated repair costs for the old pipe are increasing at the same rate as the discounted investment costs for a new one are decreasing. German water works departments replace a pipe much earlier. They do it approximately in the year in which the fourfold of the repair cost is equal to the annuity of the investment for a new pipe (see Fig. 2). Implicitely, they thereby assume that the social costs of a failure, such as damages to the customers, annoyances to the neighbours and street users, losses of company reputation etc., are about three times higher than the actual repair costs. Thus the standards set by utilities exert similar effects as network expansion or introduction of new technologies. New standards induce a wave of renewal activities, which after a life-span might repeat.

Anticipation of Pipe Renewal

In most cases pipes are not replaced because their condition is substandard or their capacity insufficient, more often other public works in the street trigger off pipe replacements earlier than would otherwise have been necessary. Herz and Hochstrate (1987) have shown that by saving or sharing the costs for repaving the street above the pipe's ditch, a time interval is gained within which coordinated renewal is cheaper than the renewal of each system separately. Another reason for anticipated pipe renewal may be to avoid imminent peaks of renewal investments, which would impinge upon construction capacities and budget constraints.

Cost of Renewal Measures

The financial demand for network renewal is certainly to a large extent determined by the specific costs of different renewal measures and their effect on the pipe's life-span. There is always a choice between an expensive solution with new durable conduits and a cheaper one, such as cement lining or relining technologies, which do not produce the life-spans of new pipes. Rehabilitation by cement lining would probably prolong a pipe's lifetime by half the time and at half the cost of a new pipe, with some minor reduction in capacity.

Even taking all these influencing factors into consideration, the actual and future demand for network renewal is by no means predetermined, but is to a considerable extent open to renewal policies and strategies, which should be tailored to the state of the existing network, to the needs of the service area and to the capabilities of the utility company.

MODELLING THE NEED FOR NETWORK RENEWAL

The need for network renewal at any time results from physical and functional ageing processes of the network elements as well as from management decisions concerning intensity and timing of renewal measures. These factors will subsequently be treated accordingly in a model of network renewal.

Renewal According to Physical Deterioration

Given the age and material structure of the existing water supply network, average life expectations are assigned to homogeneous groups of network elements. These life-spans are neither optimal in economic terms nor the most probable ones, they are merely normative in the sense that they have been set by the water works managers, and they should be closer to reality than those time-spans used in the company's balance account for depreciation. In the model, these estimated life-spans are treated as random variables, with a normal distribution and a standard deviation of 1/8 of their respective means. This is close to reality. Figure 1 shows the corresponding exit and survival functions applied to each cohort of network elements, which are homogeneous with respect to age and course of deterioration. Similarly, information on network condition, gained from inspections, could be included into the model (Herz/ Hochstrate, 1987). Furthermore, the initial investment of each element is written down on a straight line basis over its particular life-span, so that at any point of time there is an account of its real capital value.

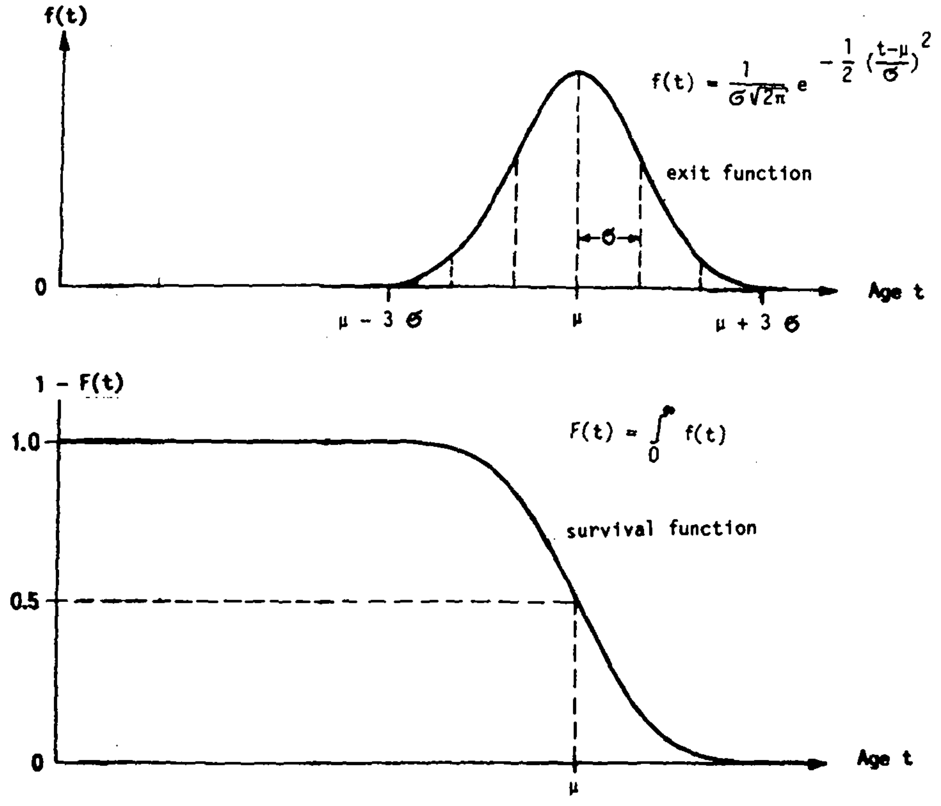


Fig. 1. Exit and survival function for homogeneous elements of the water supply network (normal distribution)

Renewal According to Reliability Standards

For simplicity it is assumed in the model that failures start at the middle of the pipe's life-span and that repair costs increase linearly from then on. At the expected end of the pipe's lifetime, they are assumed to amount to one quarter of the annuity of a new pipe (see Fig. 2). This reflects common practice in many of the larger German utility companies. Another option would be to lower the standards of network condition and reliability, expectations of pipelife would then increase: for example, if the social costs of failures were assumed to be in the same order of magnitude as the repair costs, life expectations increase in the model by 50 percent. On the other hand, there are also good reasons for raising the standards. For example, reduced water losses through leakages mean reduced ecological impacts in the water exploitation zone, and in this case, the pipe's life-span would be shorter.

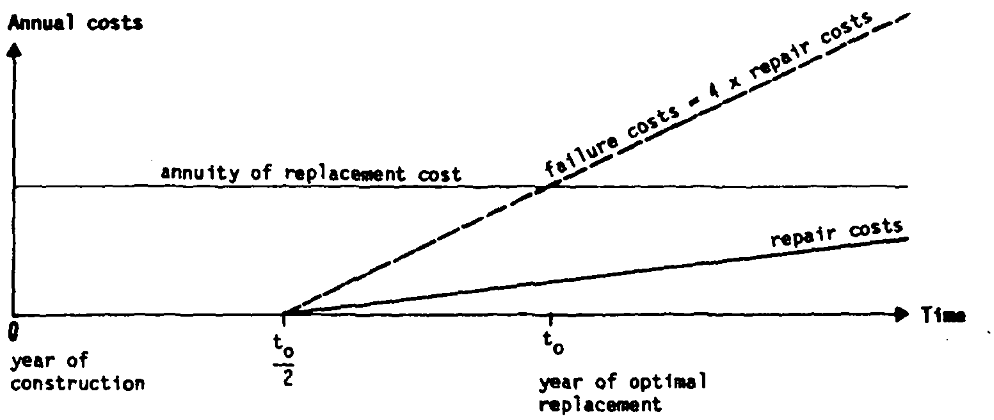


Fig. 2 Relationship between repair and failure costs and timing of replacement in the network renewal model.

Renewal for Functional and Exogenous Reasons

The replacement of water supply network elements before they reach their expected end can be handled within the model in two different ways. First, those elements of the network which are located in special areas of urban renewal or development can be separated in order to assign specific expiry dates to this part of the network. The expiration of their life-span is treated in a deterministic rather than in a stochastic manner. The second possibility is to define a certain percentage of elements with specified diameter, material etc. for advanced replacement. Because the old conduits will normally be replaced by larger new ones, in this case, there are higher renewal costs involved for this part of the network.

THE RENEWAL IMPACT MODEL

The model has been conceived as an analytical tool for the identification of an optimal network renewal strategy. The solution is found interactively by comparing financial consequences and network performance impacts resulting from different strategies.

Principle of Interactive Network Renewal Planning

In a first run the model produces long-range forecasts of annual investments and network performance indicators by ageing the existing network and applying at the start the renewal strategy practiced to date with respect to timing, measures and costs of renewal. The results of this first run reveal investment peaks, liquidity deficits, losses in real capital, increases in failures and repair costs and a reduction of the network's average life expectation, which might be unacceptable to the water works management and thus, the starting strategy is modified in subsequent runs in order to avoid some of these negative impacts. Of course such a modification may not necessarily result in an overall improvement of all indicators and therefore, a learning process takes place, which might continue until the renewal strategy cannot be improved further.

Description of the Model

The model consists of four submodels. The first describes the existing water supply network in the form of a multidimensional distribution of the network length, with respect to year of construction or renewal, material, diameter, location and, if available, condition.

The second is a kind of cohort survival model, determining how many metres of each category will come to the end of their lifetimes during any year. The surviving elements deteriorate and step by step get closer to their end.

The third introduces various kinds of renewal measures to those elements which have reached the end of their expected lifetime as well as to those which are selected for advanced renewal. It also adds new elements to the network, if the network is to be enlarged.

The fourth submodel is a kind of accounting system, which writes off year by year the network's real capital, sums up the investment costs for rehabilitation, replacement and new construction, and discounts these costs to the base year. It also calculates various performance indicators, such as annual repair costs, the change of the network's average life expectation induced by measures of renewal and expansion, the real capital of the network by balancing values added and those written off due to depreciation, and the change of the total length of the water supply network. It is based on these accounts that the policy maker will decide on the best renewal strategy (see Fig. 3).

Options of Renewal Strategies

A renewal strategy may be improved by changing the timing and type of renewal measures, the dimension and material used for the replacement of pipes and the extent of network expansion within any period of time.

In the reference strategy, renewal activities are scheduled so that some multiple of the repair costs is equal to the annuity of replacing the old pipe by a new one. Alteration of the failure cost factor will also change the optimal time of replacement. If the policy maker wants to advance or postpone renewal activities in order to avoid investment peaks or liquidity deficits, there will be opportunity costs incurred. Anticipating renewal means giving away usable lifetime and real capital, postponement induces higher repair and overall failure costs. These opportunity costs appear in the performance indicators diagram.

The choice of replacing or rehabilitating an old pipe does not only involve different costs but also different expectations of pipelife. Implicitely this decision also affects timing because the annuity of a renewal measure depends on the expected life-span of the conduit. A third choice can be made with respect to the material and diameter of the new conduits. Generally, there will be a tendency to choose larger pipes, because the additional costs are only marginal and hydrodynamic conditions usually need to be improved in water supply networks which have been set up several decades ago.

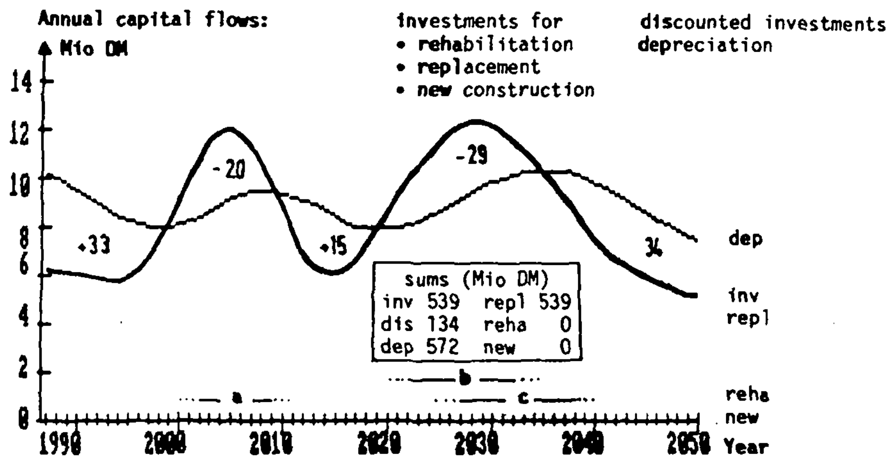
The last option is the extent to which the network will be expanded. The water works department is obliged to supply new building areas and may want to enlarge their service area. So, a certain amount of new conduits can be added to the network by category within specific periods of time.

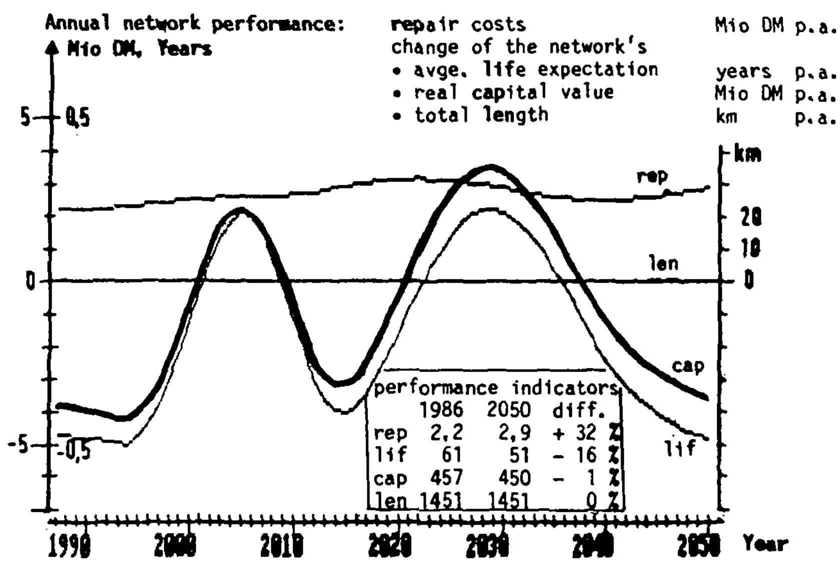
INTERACTIVE DEVELOPMENT OF A RENEWAL STRATEGY FOR THE STUTTGART WATER SUPPLY NETWORK

The model has been applied to the water supply network of the Stuttgart public utilities company TWS, which comprises 1500 kilometers of water-pipes and mains. Owing to considerable heterogeneity of material and anti-corrosion devices, average life expectations of the conduits vary between 35 and 80 years. Pronounced phases of past network expansion and different materials used during specific periods, required a differentiated forecast of the network renewal demand. The results from this model application have been documented in more detail by Hochstrate *and Endress (1986)*.

Status-quo Forecast of Renewal Investments and Network Performance

The first reference forecast reveals a considerable fluctuation of renewal investments up to the year 2050 (Fig. 3). They are mainly determined by the use of different materials in the sixties and early seventies. At the beginning of this period of expansion, the TWS shifted from cast iron to malleable cast iron without appropriate anti-corrosive protection. At the end of the seventies, the need for better anti-corrosion devices had become apparent and appropriate steps were taken. The annual capital flow curves reveal differences of up to 2 Mio DM between renewal investments and network depreciation. During the periods from 1998 to 2010 and from 2020 to 2035 the accumulated liquidity deficit will be 20 and 29 Mio DM respectively.





renewal periods due to pipe material used in the past:

a malleable cast iron without anti-corrosive protection laid between 1968 and 1973, life expectation: 35 years

b malleable cast iron with poor anti-corrosive protection laid between 1974 and 1979, life expectation: 55 years

c cast iron, laid between 1960 and 1968, life expectation: 70 years.

Fig. 3. Status-quo forecast of capital flows (above) and performance indicators (below) for the Stuttgart water supply network.

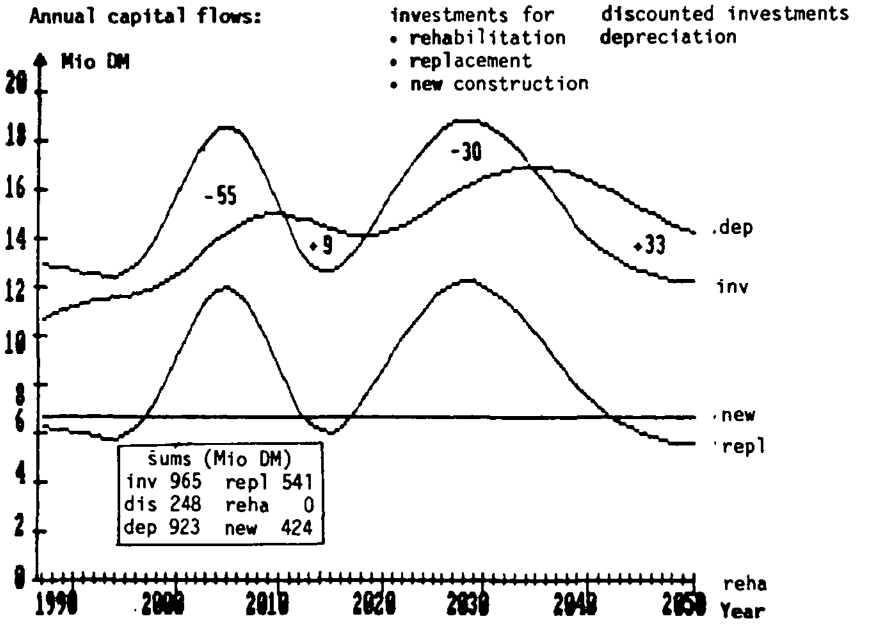


Fig. 4. Alternative forecast with network expansion for the Stuttgart water supply network

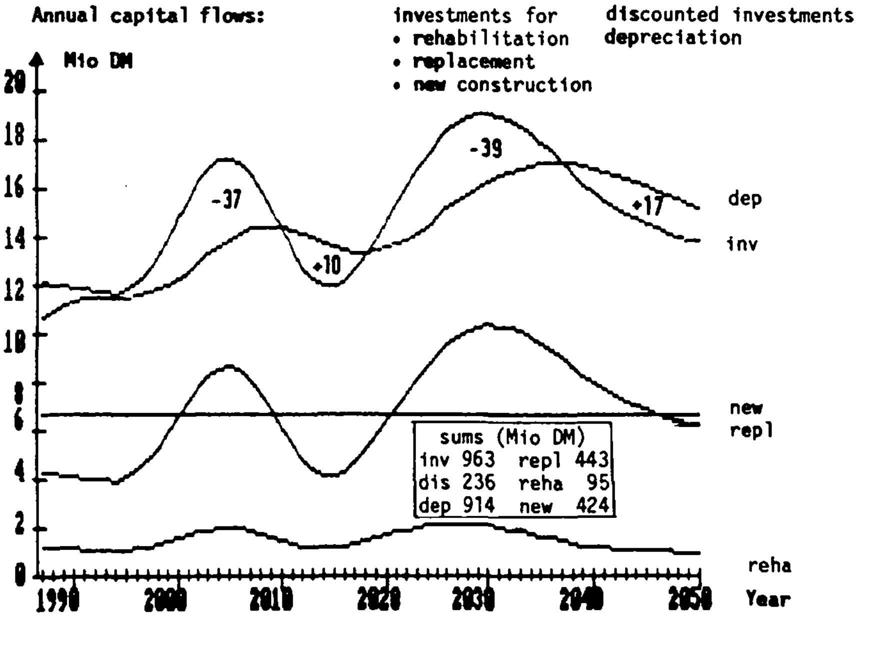


Fig. 5. Alternative forcast with network rehabilitation for the Stuttgart water supply network

The network performance indicators, change in real capital values and average life expectation, show improvement during the periods of intensive renewal investments. Since most of the water supply network has been constructed in the sixties and seventies, the average remaining lifetime gets shorter and annual repair costs increase by one third over the total forecasting period.

Forecast Including Network Expansion

During the last two decades the TWS water supply network expanded annually by an average of 12 kilometres. Assuming that the network would continue to grow at this rate, the corresponding capital flows are shown in Fig. 4. This results in an extended liquidity deficit up to the year 2010, from then on liquidity is almost the same as in the reference strategy without network expansion, that is, from 2010 onwards network expansion will finance itself by income from network depreciation.

Rehabilitation Instead of Replacement

In order to reduce the high liquidity deficits, some of the old pipes will be rehabilitated instead of being replaced by new ones. Depending on the pipes' diameters, between 30 and 100 percent of the pipes due for renewal are rehabilitated. Indeed, this strategy would reduce the liquidity deficit up to the year 2010 from 55 to 37 Mio DM (Fig. 5). However, during the following period up to the year 2035 the liquidity deficit shows an increase by 9 Mio DM in comparison with the former strategy. It is apparent that renewal activities following the prolonged life-span of the rehabilitated conduits, have to be taken into consideration.

An Acceptable Renewal Strategy

The goal of realizing network renewal and expansion with a low and constant financial load can be achieved by a renewal strategy combining rehabilitation measures during specific periods of time with advanced and postponed renewal activities. The liquidity deficit of the following strategy will be about 1.4 Mio DM per year up to the year 2035.

1985 - 1998 Prefer durable materials, no rehabilitation or low-cost measures with life expectation in the range of 30 to 50 years, no postponement of renewal activities into the period after the year 2000!

1998 - 2010 Postpone some renewal activities into the period 2010 to 2020 in order to reduce liquidity bottleneck, no rehabilitation with life prolongation by 20 to 40 years!

2010 - 2025 Carry out postponed renewal activities and use rehabilitation and low-cost technologies to prolong life-spans beyond the year 2035!

2025 - 2035 Reduce renewal investments by rehabilitation and low-cost construction and postpone renewal activities into the period after 2040!

In such a general renewal strategy, all network performance indicators will stay in an acceptable range. For more details see Hochstrate and Endress (1986).

Benefits from the Network Renewal Model

Long-term investment forecasts required for the renewal of water supply networks, supplemented by forecasts of network performance indicators, such as failure costs and real capital values, appear to provide useful information for decision makers in public utility companies for network maintenance and renewal. These forecasts depend not only on the state of the existing network but also on the renewal strategy chosen, affecting future renewal costs as well as tariff calculation and investment planning. With the model outlined in this paper, the impacts of reduced, postponed or advanced renewal measures on network reliability and repair costs can be quantified. Thus, network renewal strategies can be developed which explicitely consider these effects in the medium and long term and guarantee that the performance of the water supply network will meet the standards required.

FINAL DISCUSSION

In the near future growing attention will have to be paid to the renewal of urban water supply networks if standards of service and reliability are to be maintained. Particularly in central urban areas water mains and pipes have been laid decades ago, and considerable changes in land use and demand for drinking water have occurred since then. The demand for physical and functional network renewal will increase in the future. More money will have to be spent on the renewal than on the extension of water supply networks. Due to the age and material structure of the urban water supply networks, the demand for renewal will increase up to the year 2000. Beyond that time horizon, there will be a decrease of renewal investments, which can be forecast by the kind of model presented in this paper. Thus, investments could be directed towards renewal activities during periods of economic growth and financial liquidity on the side of public utility companies, preventing renewal investments to peak during periods with a shortage of funds.

A consistent renewal policy is needed which takes into account the processes of physical deterioration and functional depreciation of the existing network on the one hand, and which considers on the other hand measures as well which have to be conceived in order to improve the efficiency of the water supply network and meet the changing demand for water by appropriate network modification and extension.

Muddling through these problems of ageing and renewal and pursuing a fire-alarm strategy would certainly not be the adequate way to cope with these long-range processes and the enormous costs involved. It needs careful long-term analysis of the network performance and the cost for maintaining given standards. Such an analysis must be based on informations about the existing network, its capacities and conditions, and should provide an outlook to the future state of the network under different renewal strategies.

Most cities do have information on their water supply network required for the simulation of flows from well to tap. Simulation and optimization models are applied in order to improve the network structure. There is also information available on the physical condition of pipes and mains, on leakages and breaks. However, in most cases the latter type of information is neither analysed systematically nor is it used in the context of forecasting future network condition.

Inspection techniques as well as electronic and graphic data processing devices are rapidly advancing. So the information system needed for analysing and forecasting the physical condition and performance of water supply networks can be implemented at relatively low cost, low compared with the enormous investments which have to be made for maintaining past standards of service or even improving them in the future.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the German Research Foundation (DFG) for funding a one and a half year research project on urban infrastructure network renewal, and to the utility company of Stuttgart (TWS) for providing the necessary information for the application of the renewal model to their water supply network.

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SESSION 2

SEANCE 2

Chairman
Président F. FIESSINGER

- A Satisfactory Water Service Expert System
  Un système spécialisé satisfaisent de services de l'eau

  M. Kado, H. Itoh

- Computerized Troubleshooting Assisted by Expert-Systems
  Télédiagnostic Assisté par Système-Expert

  K. Douang

Discussion

"The SYMPOSIUM WATER 2000"

A SATISFACTORY WATER SERVICE EXPERT SYSTEM

Minoru Koda
Haruo Itoh
Fuji Electric Co., Ltd.
New Yurakucho Bldg. 12-1, Yurakucho
1-chome Chiyoda-ku, Tokyo 100 Japan

Phone: Tokyo (03)211-711
Telex: J22331

1. A View of the Water (Supply) in the 21st Century

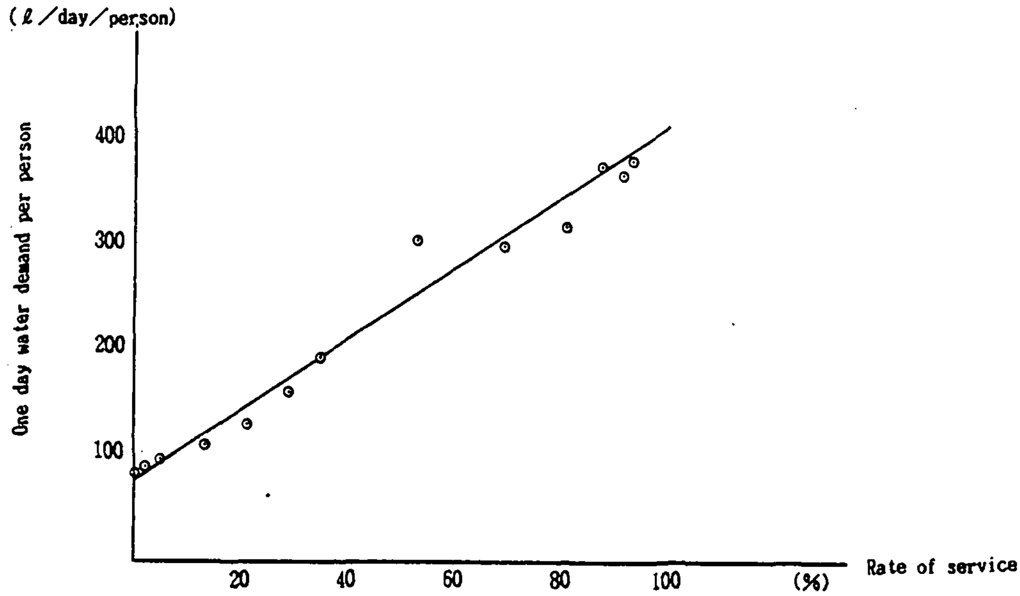
1-1 The Increase of the Water Use

In the 21st century, the water supply system will greatly expand as a sytem supplying people with water. At the regions where there is no benefit from treatment water now, the system will be installed and people will have fresh water for daily life. In country a regions where water supply systems now exist, usage of these system will increase even more.
Why? Because,

(1) the demand of water at the factories will increase, and

(2) the demand of water for other urban functions (energy supply, transportation, medical treatment, communication, product distribution, pollution treatment, waste disposal etc.), will all so.

Fig. 1 shows the increase of rate of service and the change in the amount of water use per person in Japan. The rate of water use per person will increase as the water supply service becomes more readly available.
Also, a city gets larger, the amount of water use increases in order to fulfill the city variouse functions.



from 50 years history of JWWA

Fig.1

1-2 The Increasing Instability in Quantity and Quality Due to the Increase of Water Use.

The increase of water use by people brings various changes in the natural world. The natural water cycle is, of course, inherently unstable. As the amount of water used by humans increases in relation to the natural water supply, the quantity used by humans becomes increasingly unstable.

Therefore, we say that the increase of water use brings an instability of quantity.

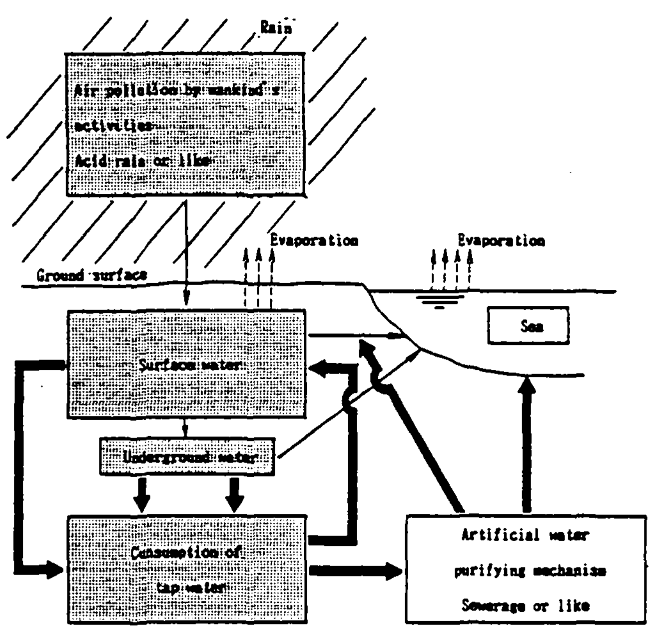


Fig.2

Fig. 3 shows the increase of the water use and the circumstances of water shortage in Japan.

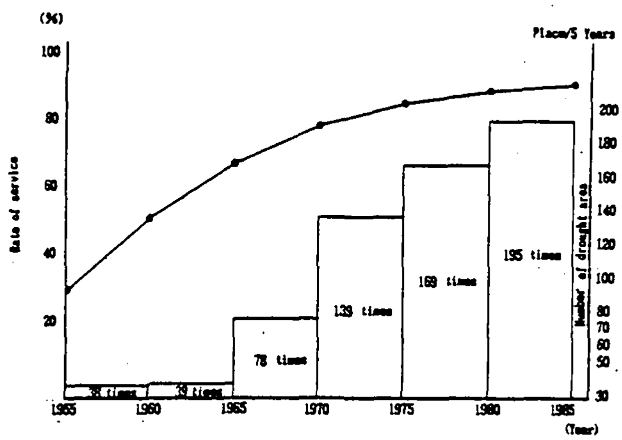


Fig.3

Next, let's deal with the instability of quality. People use water in order to melt, to dilute, to wash, to cool, to transport, to drink etc. As a result, this water contains pollutants. So, when the polluted water re-entered to the natural water cycle, the quality of natural water rapidly becomes polluted too. And as the amount of reentering water increases, the quality's instability increases as a matter of course.

We have data that proves the amount of water in use affects the pollution level of the river.

These increase of the quantity's and quality's instableness is affected by these conditions:

(1) the region's climate (rainfall, the amount of precipitation during seasons, the circumstances of underground water, the circumstances of snowfall)

(2) the region's geographical features

(3) the region's industry, size of the population,

(4) the region's custom and water usage patterns due to the region's historical background of its water and people.

1-3 The Demand for a Stable Supply of Water in the City.

We'll look at what purposes water is used in Japan's capital, Tokyo. The amount of water used in one day in Tokyo is 480 x 10^4 m^3. The amount used by each family is 240 liters per day per person, and the population of water supply using people is 1081 x 10^4, so 259 x 10^4 m^3 per day is used. And the rest of it 221 x 10^4 m^3 is used by government offices, companies, hospitals, schools, factories, shops.
This result of information tells us that water is not only used by individuals at home but also used in order to maintain the function of the city.

As we see, in the 21st century, the water supply of the city at least must supply these function as a city:

(1) energy supplying system

(2) information and communication services

(3) transportation and material distribution systems

(4) medical treatment and calamity precautions such as a fire service

(5) environment preservation system (parks, waste disposal, etc.)

Necessarily, these water supplying systems are linked. These systems mutually depend on each other's effectiveness and safety. Whenever one of the system's safety levels declines, it might cause the whole city's safety level to decline.

On March 21st, 1986, Japan's Kanagawa prefecture's region was shocked by a great snow storm and a power cable tower crashed. It caused a black-out for 24 hours.

600,000 households were without water for about 20 hours. This accident with the energy supplying system menaced the water supplying system. Also at this time, people living in tall apartment building felt strongly that the effects from the without their water supply was not the drinking water, which was considered originally the most basic water demand, but, being

unable to use water for the disposal badily waste.
In the city, the priorities for a water supply seem to have changed. The demand of a city's water supply, becomes more pronounced when the city becomes larger.

1-4 The Problems in Regions with newly Installed Water Supply System

I stated before, in the 21st, century more people in the world will use water. Becuase of that Each country must secure a water source, construct the water transportation system and water managing system. So each country must maintain fund for construction of facilities. Furthermore, worker to be educated and retained. More important than the construction stage, is the operating stage. The water facilities must be operated and maintained for a long time for 10 or 20 years.

During this lengthly period, long time, the environment surrounding the water source might change and affect the quality of water. Or there may be change with the water transportation system or changes with the pump. Furthermore, water supply system needs a careful operation and maintenance, in every days.

In that stage, it is best to educate the workers of their own nation for management and operation. And, this is efficient when the worker is native because he is sensitive to the domestic concerns about water. They can correspond appropriately to the demand of the safety of water supply as the use of it increases, stated in (1-2) and (1-3).

2. Problems and Solutions

We estimated the water supply situation in the 21st century in the chapter (1) of this paper. For its problems, we identified:

(1) The diffusion of water supply and the increasing use of water creating greater instableness in quantity and quality.
(2) The water supply in the city gives important influence on the city's various functions.

(3) As the diffusion of a water supply progresses, there is a necessity to maintain more professional workers in the given region.

Now, 1 would like to state ways to solve these problems.

2-1 A Counterplan for Water Quantity Stabilize

For stabilizing the amount of water these things are needed:

(1) facilities such as dams and reservoirs which stabilize changes according to the season.

(2) facilities such as a water transportation system which can be covered demands of water.

For these, we can drow upon the skills and technology of the 20th century. We want to stress here, not the simplified form of a water supplying system composed of 1 water source and 1 water transportation system, but a system, which can respond to various situations at any time. Such a water transportation system is to be linked functionally by many water sources, each with different characteristics.

This concept of a system must have a good grasp of water sources, demands, facilities' operating circumstances at all times. Such a concept must be able to make projections about a given situation 2 to 3 weeks in advance, and then transport the water accordingly. The function for managing such information is necessary. I think 21st century the tecnology of will enable this fully.

2-2 A Counterplan for Water Quality Stabilization

The human being used water for a long time depending on the natural purification phenomenon. In Japan, when we were going to construct the water facilities, we used to select water source which has stabilized quality of water.

Therefore, as far as the most water purification plants were concerned, they have been enough to remove of turbidity and chlorination for supply water. But as stated before in this paper

(1-2), instability of quality is increasing because pollution has increased due to the increase in demand accompanied by a decrease in water source in good condition.

Instability due to pollution can clearly be observed by considering the accident of the Reine River.

Judging from these condition, we shall be considered the counterplan for water supply system as follows.

(1) To endevor to keep of observation and preservation of the environment of the water source.
(2) To construct of a system which is able to stop water abstraction if pollution occurs and to secure that the water supply meets minimum essential demand during the stoppage of water abstraction.
(3) To complete of treatment method for poisonous substance.
(4) To construct of a system to separately supply water used for people's health.
(5) To be treated by the users according to their needs.

These counterplans should be adopted is decided by;
(1) situation of pollution's progress
(2) ability of techniques and the cost performance for each counterplans
(3) level of user's sense of public concern
(4) customs of citizens' usage for the water

However, without the application of management of information system, there are many difficulties of management and operation.

2-3 The Improvement of Inspection and Maintenance of Equipment

Current water facilities have pumps, various chemical feeder, many other machines, plus electrical instruments for controls. In order to operate all the water facilities efficiently and safely, we must inspect and maintain these equipments. It is desirable to know in advance whether the equipment will require extra parts or not, whenever we aim for the improvement of safety for a water supplying system. Therefore, we must keep a record of operational circumstances of machines and a form which decides the time and the degree of repairs or maintenance. With this in mind the management of information system seems to take on an important roll in the maintenance of machines.

2-4 The Education of Staff and Improvement of Skills

I have stated that, there is a necessity to educate many professional workers in the new region as the improvement of service of water supply in the 21st century takes place. By the way, like the water supply, which is greatly affected by the circumstances of nature and society, it is very hard to measure one cause which to decide one thing. More than that, there are too many factors we must consider, and many cases causes and effects are still not explained. In this kind of situation, the training is only done by the experiences actual thing.

Plus that, often, this may not work in other regions which were considered correct in one country or one region. It is because there are different customs, conventions and laws formed a long time ago between people and water in each country or region. Therefore, I think the staff education should correspond to regional circumstances except for extremely basic things.

Education should take place on location, taking into account daily particualrs.

In this way, the result of daily operation and the effect of plans for accidents will become very practical for training. And so, daily operation report and other data should be readily available upon request.

2-5 Expectations for the Expert System

In this chapter, we will explain that the information processing system will play an important part in the following;

(1) The stability of quality and quantity of the water supply system.

(2) The improvement of inspection and maintenance of equipment.

(3) The education of water supply workers on location.

It becomes a matter of question whether Age of information in the 21st century could progress to the stage where it can respond to the demand of water supply system, but I don't think it's impossible.

The information industry with the computer as a basis is progressing rapidly. Artificial-Intelligence has started to be elucidated by many researchers in fields such as language comprehension, pattern acknowledgement, self learning, expert system which are considered especially valuable in the realm of the information industry. Expert system is still in the stage of development, but it has just begun to be used in the field of medicine and maintenance of equipment. I think this Expert system will become a powerful weapon for solving the problems of water supply in the 21st century.

3. Summary of the Expert System

The Expert System is a system that solves the problems of using a computer in the following areas;

(1) Programming is difficult unless one has computer domain-specific knowledge.

(2) Processing of date with non-numeric values is difficult.

(3) Improvements and reorganization of domain-specific knowledge is difficult.

Thereupon, the specialist systemize all his knowledge (computerize) without programming skills and cultivation of this knowledge becomes possible. Also, because of the systemization, a non-specialist by freely being able to use the Expert System work on the same tasks as the specialists.

The following effects can be expected of the Expert System in the advancement of the water service industry;

(1) We can deal with the water distribution control and/or the water treatment which are difficult to obtain specialized algorithms.

(2) Average level's operation can be dealt with even in the event that the specialist is absent through the obtaining selectable answer.

(3) The system will be completed as the specialist, which considers regional characteristic, through taking into its mind on itself.

(4) The operator will be educated for the specialist by the Expert System which explains as a specialist its conclusion and/or advice.

The general concept of the Expert System is described is Fig. 4.

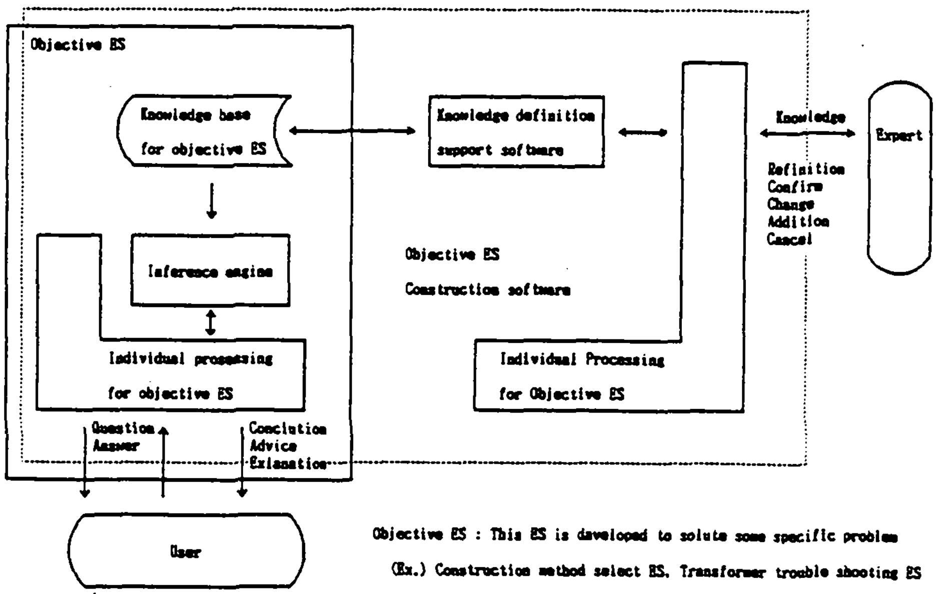
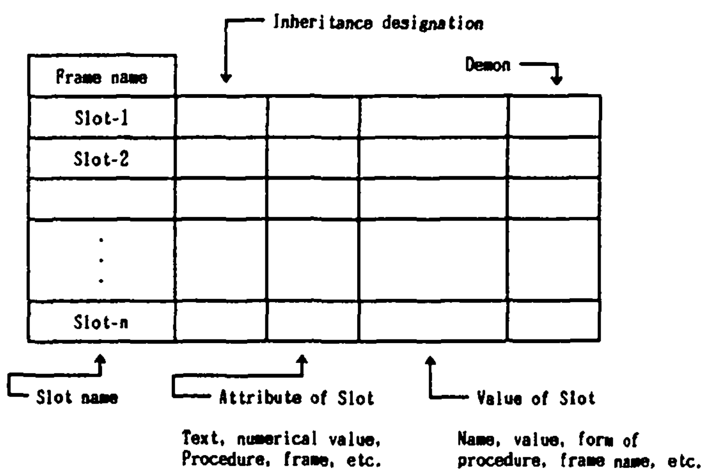


Fig.4 The general concept of the Expert System

At present there are researches being carried out in the field of A.1. (Artificial Intelligence) in the form of what is called knowledge representation and here we will introduce a representative example of this.

3-1 The Frame-based System

The knowledge base system designed based on M. Minsky's Frame theory is explained. The unit of knowledge representation is composed of a data structure called a frame and this is represented in a subset of a formation of elements called a slot. Distinctive features of the Frame-based system is that the representative unit of data is comparatively large, is taxonomically composed of class structures, is represented by a mixture of declarative knowledge and procedural knowledge, a specific inference control mechanism is not incorporated, and the reasoning is executed in a object directive method called a message exchange within the frame. The general concept of the Frame-based system is shown in Fig. 5.



from Knowledge base system, Department of Technology, Tokyo, 1985.

Fig.5 The general concept of the Frame-based system

We can also show you the practical application example of this system, which is used for equipment problem diagnosis. But we omit it from this paper, as there is not enough space for a complete description.

3-2 Production System

In the Production system, the knowledge is represent by rules. Basically, the rules are described the IF...THEN format. The IF unit is called the premise unit and the THEN unit is called the conclusion unit. The Production system structure is shown in Fig. 6. The rule base stores the described knowledge in the premise → conclusion or condition → action format.

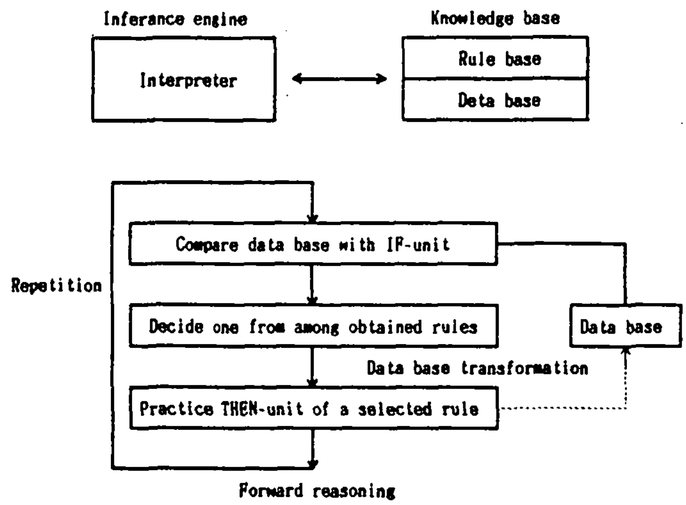


Fig.6 The Production system structure

The working memory is a subset of the data that is subjected to reference and alteration by the production. The working memory is a data base or can also be called the context. The interpreter observes both the rule base and the working memory and searches for a production subset that waits to compare the working memory, then selects the most suitable one for the present context and manages the execution of it.

We have a practical application example by this system, which is used for optimum application of a large scale water supply and distribution line system, but we omit it in this paper, as there is not enough space for a complete description.

3-3 Fuzzy System

The beginning of the Fuzzy theory was in 1965 at the University of California, when Professor L. A. Zedeh presented Fuzzy theory of sets. The concept of Fuzzy is as follows. In order to express the vagueness that humans have, the membership function is used in Fuzzy. With methods up until then there was only a distinct choice between whether a concept was completely applicable or entirely non-applicable. In mathematical terms a 0 or a 1. For example, in order to present the concept of a temperature being a little high, the range between 22.5 degrees and 27.5 degrees was defined as "a little high". However, when we say "a little high", there is no distinct boundary. The area around the middle 25 degree is actually presented. As we deviate from the 25 degrees, the angle (degree) becomes smaller. Mathematically, we are expressing the certainty with a function. This function is called a membership function. Triangles, index functions and special functions are used.

With the expression of vagueness with the concept of the membership function we can represent half applicable, very applicable, and a little applicable with the numerical values of between 0 through 1. In other worlds, if 0 then it is completely non-applicable and if 1 then completely applicable. Values between will correspond accordingly.

With this, an expression more familiar to the human method of judgement is possible more so than the mathematical methods available up until the present. This is the method of expressing vagueness with a function.

With the Fuzzy reasoning, the fragmented experiences and the conditions and results (input output relation) that are the basis for human knowledge is expressed in the IF THEN format (IF ∿ THEN do ∿) and when a condition is given the results are sought. As a distinctive feature of this is that, the premise (IF unit) of the readied control rules is completely evaluated and with the validity as a weight, the operations that are instructed by each control rule are consolidated and finally the operation volume is decided upon.

Another feature of the Fuzzy reasoning is that what ever happens, the reasoning results can be obtained. In other words, an analogy is possible.

Even in knowledge engineering, the IF THEN format is widely used. However, the basis for this reasoning is syllogistical and searches out 1 rule (control rule) that satisfies the condition and the instruction for that rule becomes the reasoning results. Thereupon, the reasoning is basically a matching operation and is different from the Fuzzy numerical value operation. Because of this, basically solutions other than the ones prepared cannot be obtained and an analogy is not realizable. In addition, since vagueness is introduced into the Fuzzy control rules, the effect of requiring less control rules can be obtained and designing becomes easy. On the other hand, because in knowledge engineering control rules to handle all cases must be created the number of control rules are many.

Fig. 7 shows the Fuzzy control system concept.

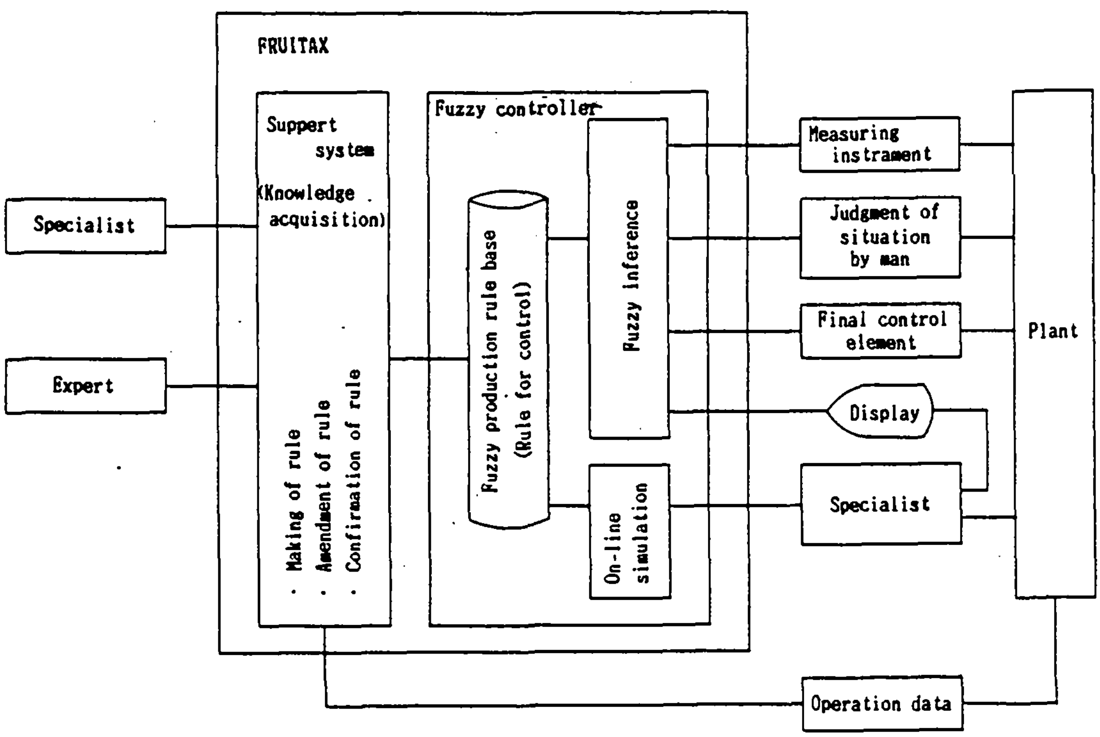


Fig.7 Fuzzy control system concept

4. Representative Example of the Fuzzy System

As an application example of the Fuzzy theory, this paragraph describes the coagulant feed ratio control in the turbidity impurities coagulation process in a water purification plant.

• Coagulant feed ratio control in a water purification plant

The coagulant feed ratio control is an important process to generate a high-quality flock (coagulated impurities) against the change in raw water quality and eliminates the impurities by sedimentation and filteration.

However, as the process of reaction between the coagulant and the impurities is very complex, a complicated method has not yet been proposed. At present, the feed ratio is decided by rough status judgement and accumulated experiences based on the jar test results and the feed ratios known by statistics and experiences.

• System Configuration

The coagulant feed Fuzzy controller consisting of the system shown in Fig. 8 performs the inference calculation by handling the operator's status judgement as an input, in addition to the values measured in each process. The method of calculation the feed ratio is shown in Fig. 9. On the basis of the feed ratios obtained by statistical processing of past data, the system infers the elements not covered by the formula (e.g., bad coagulation of impurities, extreme increase of the impurities at the start of plant operation, and other elements depending on the plant conditions) and calculates the correction amount by the Fuzzy theory.

• Field test results and ideas

Table 1 shows the results of the hearing research done before the field test and the original plan for control rules drafted

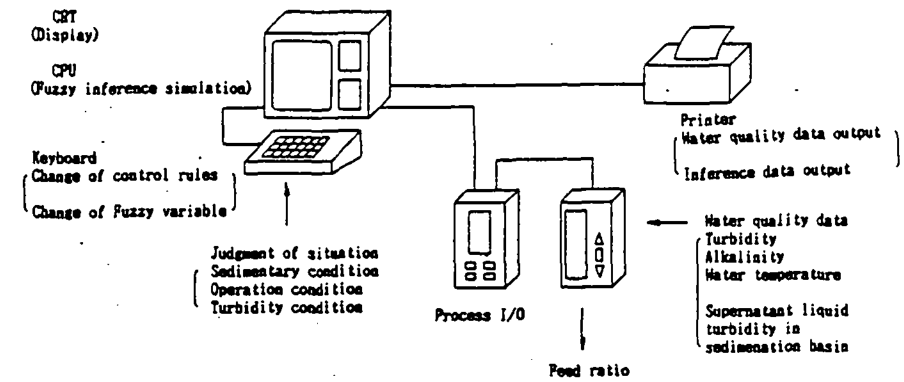


Fig.8 The coagulant feed Fuzzy controller in water purification plant

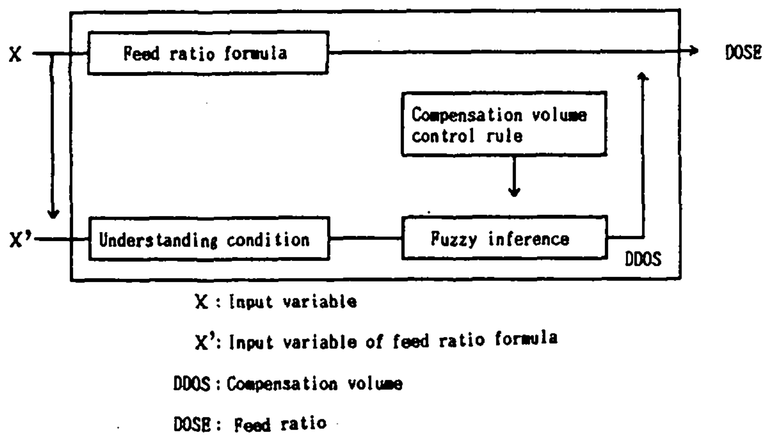


Fig.9 The method of calculation the feed ratio

based on the results. Table 2 shows the exact control rules established by improving the original plan based on the actual data. As seen from the 2 tables, the hearing research often makes a partial rule only. Improvement and verification based on the actual data are necessary to establish a complete rule. A universal fuzzy control system performs this task efficiently by using a suitable support system.

Note that in the field test, the operator set the coagulant ;feed ratio with the jar test results and experienced judgement. The test was executed by comparing the feed ratio set in this way with the value inferred by the Fuzzy controller.

Findings of feed ratio convensation volume (DOOS)	· If raw water turbidity (TUI) is very low (SS), then do plus(PM) feed ratio converstion volume. · If alkalinity (ALK) is low(SA), then do minus(MM) it. · If supernatant liquid turbidity in sedimentation basin(TUSE) is high(LA), then do plus it. · If raw water turbidity up(TUUP) is high(LA), then do plus it. · If folc(FLOC) is small(SA), then do plus it. · If operation starts in intermittent(STAT), then do little plus(PS) it. Symbol patled in quotes are name of input variable or Fuzzy variable.
Control rule	① IF TUI = SS THEN DOOS = PM ② IF ALK = SA THEN DOOS = NM ③ IF TUSE = LA THEN DOOS = PM ④ IF TUUP = LA THEN DOOS = PM ⑤ IF FLOC = SA THEN DOOS = PM ⑥ IF STAT = LA THEN DOOS = PS

Table 1. The result of the hearing research and control rule

① IF TUI = SS			THEN DOOS = PM
② IF TUI = MM	TUSE = ⌐LA	TEMP = ⌐SA	THEN DOOS = MM
③ IF TUI = SA	ALK = SA	TEMP = SA	THEN DOOS = MM
④ IF TUI = LA	ALK = SA		THEN DOOS = MM
⑤ IF TUSE = LA			THEN DOOS = PM
⑥ IF TUUP = LL			THEN DOOS = PB
⑦ IF TUUP = ML			THEN DOOS = PM
⑧ IF TUUP = MM			THEN DOOS = PS
⑨ IF FLOC = SA			THEN DOOS = PM
⑩ IF STAT = LA			THEN DOOS = PS

LL : very high, ML : high, PB : very much
MM : midium, ⌐ : negation

Table 2. The exact control rules based on the actual data

A part of the results of the 1 month test is shown in Fig. 10. The equation to calculate the feed ratio is obtained from the average trend of the original data. It cannot exactly follow special phenomena such as extreme increases in raw water turbidity. But as the operator's judgement is adopted as an input in the Fuzzy control, even special phenomena can be sufficiently covered. This is also indicated by the residual square sum and the residual standard deviation of table 3. The Fuzzy inference is proved effective by these data. The residual value is obtained as a difference between the estimated feed ratio and the actual feed ratio calculated by the Fuzzy theory of the equation.

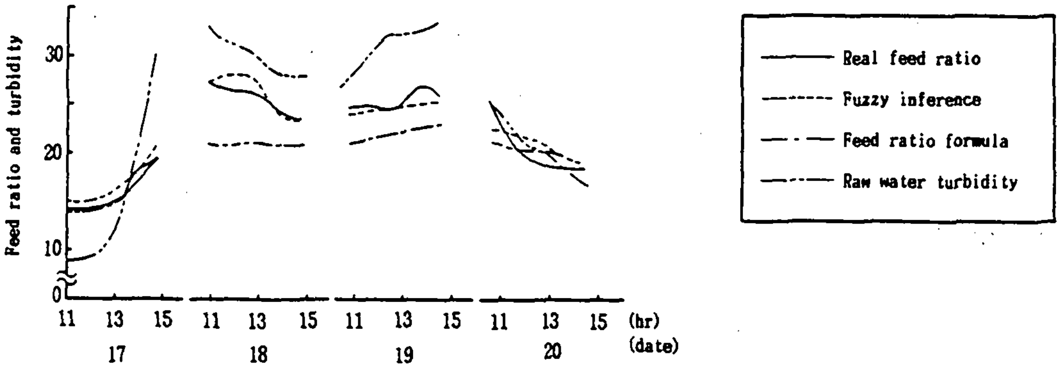


Fig.10 Theresult of field test

Classification	Feed ratio formula	Fuzzy inference
Residual square sum	628	224
Residual standard deviation	2.28	1.36
The number of times of which Fuzzy controller is better than operator	33	41
The number of times of which Fuzzy controller is worse than operator	41	33

Table.3 Analysis result by field test

Table 3 shows good cases where the residual value obtained by the Fuzzy theory or the equation to calculate the feed ratio is close to the mean value, and bad cases where the opposite tendency is seen, taking the mean value of the turbidity of the supernatant liquid of the sedimentation basin as a control goal. It can also be seen here that the Fuzzy inference is superior to the feed ratio formula alone and more valid than the rate decided by a skilled operator. The reason is that while even a skilled operator can not always make a correct judgement, the Fuzzy control permits forming the control rules based on the optimum operation data and can reproduces it at any time. The above statements point out that the control rule can be easily improved, the inference value of the coagulant feed ratio Fuzzy controller matches with the results concluded by a skilled operator, and the feed ratio is more correct than that obtained by simple equations to calculate the feed ratio. The possibility of exceeding the skilled operator's routine operation is also suggested.

The reasons can be summarized in the following points:

(1) Based on the skilled operator's operational data, the optimum Fuzzy variables and control rule can be designed. In addition, the control rule can be easily modified to meet the operational objective.

(2) The Fuzzy control permits inference including the operator's status judgements that are not considered in the feed ratio formula.

(3) Even a skilled operator cannot always make a correct judgement. The Fuzzy controller can always reproduce a correct inference based on the data set correctly.

5. Conclusion

On the presumption that in the 21st century water services will increase and the use of water will become more convenient the following problems may arise,

(1) Water use will increase

(2) Because of the increased use, the water supply will become unstable in quantity and quality,

(3) On the consumer side, the demand for stable supply will increase.

(4) There will a need to train more specialist in the field of water supply.

In order to solve these problem, the water service must not only build and maintain equipment but also apply it's own information exchange system and have explain this. We also have stated that for this reason that within the present information processing technology the Expert System now being researched is the most powerful resource. As for the Expert System, we have introduced how human knowledge, the core of the system, is expressed by being categorized, and processed to enable input into the computer. We have also introduced have the recent direction and trial applications of the Expert System in Japan. As you can see, in the examples that we have given on the Expert system, we are only in the beginning stages and only a limited field can be covered. The system's contents are only within the domain of procedures that combine data base reference and a man-machine interface. The experiments on the Expert Systems will continued to be carried out deeper into the field of information processing. However, we in the field of water service would like to see it brought up with due considerations to the special characteristics of the water service (enabling learning of area distinctive technology or experience related technology, for example), in a fool-proof system that will be stable over a long period of time.

TELEDIAGNOSTIC ASSISTE PAR SYSTEME-EXPERT

Kongkeo DOUANG

Compagnie Générale de Chauffe
118-120 rue de Rivoli
75001 PARIS
FRANCE

RESUME

L'analyse de la pratique actuelle du diagnostic technique nous a conduit à penser qu'il y a un intérêt économique à automatiser autant que possible les procédures de diagnostic utilisées par les experts.

En conséquence, nous avons travaillé dans deux directions :

- mettre au point un système-expert spécialisé dans le diagnostic de machines de production de type mécanique, hydraulique, électrique ou thermodynamique sachant aussi bien exploiter des connaissances de surfaces formulables en règles de type " Si ... alors ... " que des connaissances en profondeur concernant la description structurelle et fonctionnelle de la machine à surveiller.

- imaginer l'intégration de ce système-expert dans une procédure semi-automatique de "télédiagnostic assisté par ordinateur" comportant la chaîne complète de télémesures/détection de défaut/Analyse/Intervention.

L'ensemble de la procédure a été mis au point par la Compagnie Générale de Chauffe pour une installation thermique, mais de nombreux concepts développés dans cet article sont tout à fait transposables à d'autres domaines.

MOTS-CLES

Télésurveillance, Diagnostic, Système-Expert, Maintenance, Automatisation.

INTRODUCTION

Pourquoi la Compagnie Générale de Chauffe s'intéresse-t-elle au télédiagnostic et aux systèmes-experts ?

Cet intérêt apparemment surprenant pour certains n'est en fait qu'une conséquence logique des activités de service qu'offre déjà notre Société.

En effet, depuis plus de 10 ans nous faisons de la télésurveillance industrielle qui nous permet, par l'intermédiaire de nos postes centraux, de détecter 24 H/24 H des arrêts ou défauts de fonctionnement de machines de nos clients, de les prévenir aussitôt, et d'intervenir sur leurs installations afin de les remettre en état de marche dans les meilleurs délais.

Aujourd'hui nous souhaitons améliorer encore plus la qualité de ce service, c'est-à-dire par exemple :

- non plus seulement prévenir qu'il y a arrêt anormal de la chaudière A, mais aussi de signaler que c'est la pompe d'alimentation en fuel qui est en panne.
- non pas seulement se contenter de constater que la performance de la machine de production d'eau glacée B dérive à la baisse mais aussi informer l'exploitant qu'il lui manque du fréon.
- etc., etc...

Afin d'arriver à cette performance nous sommes en train de développer un certain nombre de techniques parmi lesquelles la modélisation/simulation/optimisation, l'analyse statistique des données, les systèmes-experts.

Autrement dit, dans le processus classique "DETECTION/ANALYSE/INTERVENTION" d'une maintenance corrective ou prédictive, nous consacrons la majeure partie de nos efforts de développement à la mise au point d'outils d'analyse.

Dans cet exposé, nous traiterons essentiellement des réflexions menées autour des problèmes de diagnostic, de systèmes-experts de diagnostic et de leur intégration dans un environnement industriel ; réflexions qui nous ont conduits à faire un choix technique original d'une procédure de "**télédiagnostic assisté par système expert**" dont il est question ci-après.

LE DIAGNOSTIC AUJOURD'HUI

Que diagnostique-t-on ?

Quand on parle d'une machine de production on a souvent tendance à associer implicitement au verbe "DIAGNOSTIQUER" un complément apparemment naturel "PANNE" (dans le sens d'un arrêt accidentel de ladite machine).

De fait, il est vrai qu'un arrêt de machine de production peut coûter cher, et même très cher (manque à gagner, pénalités de retard, perte de production...) à un industriel ; la rapidité de son diagnostic se révèle donc incontestablement d'une importance primordiale.

Cependant, de par nos expériences d'exploitants, nous sommes également très sensibles à d'autres défauts tels que :

- certaines dérives de fonctionnement (température constamment trop haute, vibration trop forte...)

- des dérives de performances (rendement, efficacité, puissance...)

Ces défauts ne revêtent certes pas de caractère urgent mais peuvent cependant avoir des conséquences économiques très importantes.

Exemples :

- Une machine de production d'eau glacée de 1 MW frigorifique et d'une performance de 2,5 voit dériver sa performance à 2,3. Elle consomme 35 KW de plus. Si elle fonctionne 8000 heures/an et si le coût moyen du Kwh électrique vaut 25 centimes, alors l'industriel doit débourser 70 KF supplémentaires par an pour son exploitation.

- Une machine ayant un niveau de vibration trop important peut comporter des défauts mécaniques capables de provoquer des dégâts importants pouvant aller jusqu'à la casse de cette machine.

C'est pourquoi il est souhaitable de ne plus se limiter aux pannes mais d'étendre l'action du diagnostic à l'ensemble des **défauts détectables**, de passer ainsi du domaine de la **maintenance corrective** à celui de la **maintenance prédictive.**

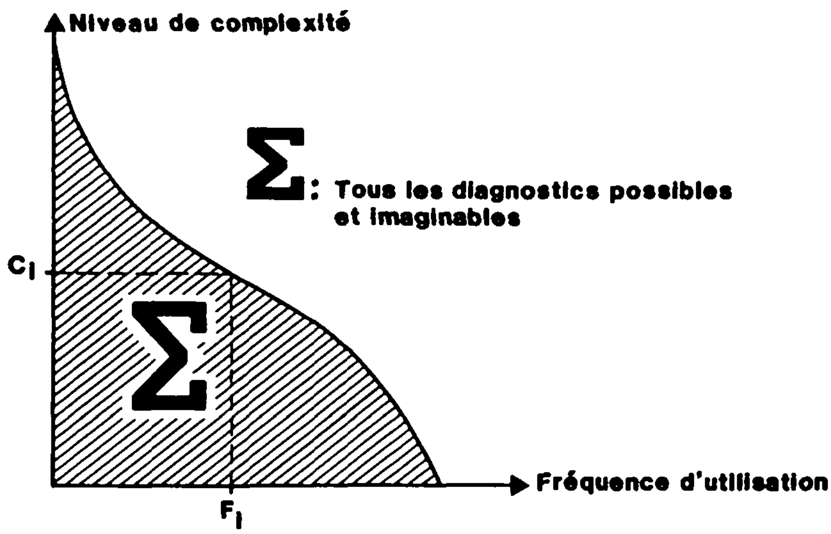


Fig. 1 : Essais de schématisation des procédures de diagnostic

Essais de schématisation des diagnostics

Lorsqu'un expert-diagnostiqueur recherche la cause d'un défaut de fonctionnement, il met en oeuvre un certain nombre de procédures de diagnostics élémentaires plus ou moins complexes.

On comprend aisément qu'il utilisera de manière plus fréquente les procédures les plus simples de préférence aux plus complexes.

Ainsi, si on essaie de classer les procédures de diagnostic par degré de complexité Ci et de trouver une corrélation avec leur fréquence d'utilisation Fi on aboutit vraisemblablement à une courbe ayant l'allure de la figure 1 dont la surface Σ représente tous les diagnostics possibles et imaginables.

Le diagnostic d'aujourd'hui : un sous-emploi de l'expert et un surcoût de la maintenance pour l'industriel

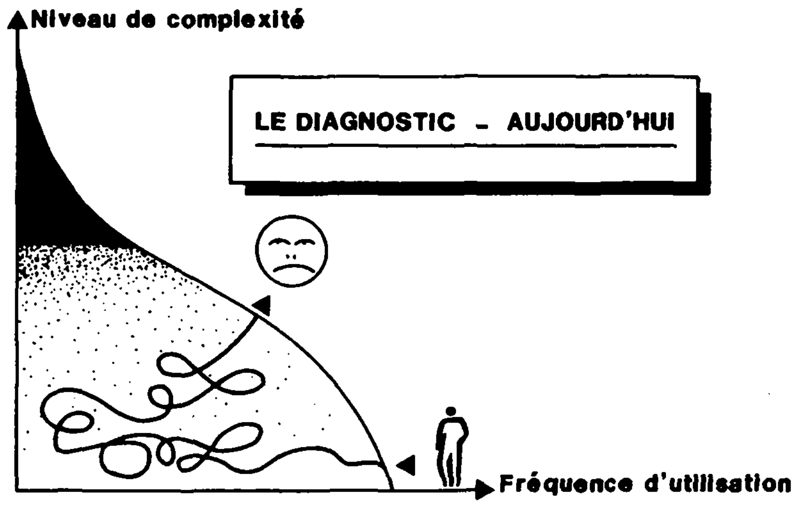


Fig. 2 : Le Diagnostic d'aujourd'hui :
un sous-emploi de l'expert , un surcoût de maintenance pour l'industriel

Pour une machine et un "expert-diagnostiqueur" donnés, nous pouvons distinguer trois parties sur le schéma de représentation des diagnostics (Fig. 2) :

- les procédures les plus complexes (en noir) que l'expert en question ne connaît pas du tout.

- les procédures simples (en blanc à la base du graphique) que l'expert maîtrise parfaitement.

- entre deux, la parties des procédures qu'il connaît plus ou moins et qui lui demande des efforts d'investigation plus importants pour les mettre en oeuvre.

Comment procède-t-il concrètement ?

Evidemment, il commence par mettre en application les procédures, des plus simples aux plus compliquées, par un cheminement plus ou moins tortueux.

Quelles sont les issues possibles ?

- ou bien le diagnostic se révèle très simple et alors quelle dépense inutile pour l'industriel (déplacement d'un spécialiste) et quelle déception pour l'expert ! ("Me faire déplacer pour une pareille bêtise, franchement ...").

- ou bien le diagnostic se révèle compliqué et lorsque l'expert atteint la fin de son cheminement laborieux, il n'est plus au mieux de sa forme pour affronter la difficulté. Dans le cas où il trouve enfin la cause du défaut, il est satisfait ... sinon il faut bien qu'il revienne le lendemain, plutôt nerveux.

Donc dans tous les cas, cette pratique **coûte cher à l'industriel et motive peu** le diagnostiqueur.

L'APPORT DE L'INTELLIGENCE ARTIFICIELLE

S.E.DIAG. : un système-expert taillé sur mesure

Après l'analyse de la pratique de diagnostic d'aujourd'hui et face à un problème industriel, nous voulons apporter une solution industrielle.

C'est la raison pour laquelle nous nous sommes associés au **Laboratoire d'Automatique Industrielle et Humaine de l'Université de Valenciennes** pour développer un système-expert spécialisé en diagnostic de machines de production de type mécanique, hydraulique, électrique ou thermodynamique : **S.E.DIAG.**

La particularité de ce système-expert se reflète à deux niveaux :

La structuration de sa base de connaissance. En effet, nous avons pensé que l'utilisation des seules connaissances d'expertises formulables en règles de production de type "Si ... alors ..." semble être mal adaptée au problème de diagnostic technique pour les raisons suivantes :

- Il y a un risque d'explosion du nombre de règles et une difficulté de vérification de leur cohérence qui croît avec leur nombre.
- On constate que sur des machines citées, un expert-diagnostiqueur n'utilise pas seulement des connaissances de type "Si ... alors ..." mais aussi des connaissances en profondeur concernant la structure même de la machine, de l'agencement entre ses différents composants élémentaires ainsi que de leur fonction respective.
- Que faire lorsque l'on a à diagnostiquer une machine nouvelle sur laquelle on ne dispose encore d'aucune expérience ?

En conséquence, nous avons structuré la base de connaissances de **S.E.DIAG** en deux couches distinctes la première constituée par des connaissances de surface formulées sous forme de règles de type "Si ... alors ...", et la deuxième renfermant toute la description structurelle et fonctionnelle de la machine à diagnostiquer.

Au niveau du moteur d'inférence. Le moteur d'inférence est programmé selon une démarche intellectuelle que nous voulons être la plus proche possible de celle d'un expert-diagnostiqueur lorsqu'il se trouve en face d'un défaut. Il commence par se référer à son expérience, à son vécu :

"**Si** je constate un tel défaut **alors** il est possible que tel **ou** tel composant soit défectueux"

C'est la phase de soupçons au cours de laquelle le moteur d'inférence exploite la couche de connaissances de surface. Ensuite, il faut qu'il vérifie si ses soupçons sont fondés ou non en explorant l'environnement physique immédiat du composant soupçonné, quitte à remonter aux composants se trouvant en amont de celui-ci. C'est en exploitant la description structurelle et fonctionnelle de la machine contenue dans la deuxième couche de connaissances que ce système-expert peut réaliser cette tâche de vérification.

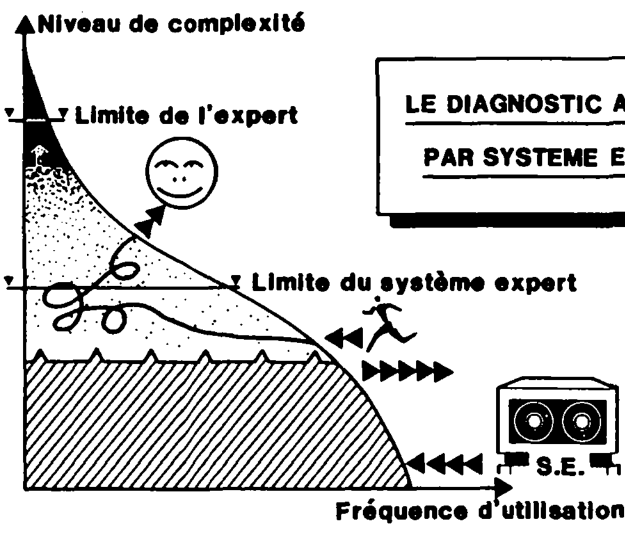


Fig. 3 : Le diagnostic de demain :
Expert + système-expert = Equipe de choc efficace, rapide, économique et évolutive

<u>**Le diagnostic de demain : expert + système expert = équipe de choc**</u>

Le système-expert exécute à la place de l'expert les diagnostics les plus triviaux pour celui-ci de manière automatique et à une vitesse de loin supérieure. Lorsque la cause du défaut de fonctionnement n'est toujours pas trouvée et que **S.E.DIAG** arrive déjà à ses limites de connaissances, il fait appel à son maître : l'expert en personne. Ainsi l'expert-diagnostiqueur ne s'attaque au problème que lorsque la difficulté est à la hauteur de sa compétence. Il est toujours frais pour affronter la difficulté et réalise forcément une meilleure performance. Et comme il travaille toujours à son meilleur niveau, il ne peut que progresser. En conséquence, il y a de plus en plus de procédures qui lui sont habituelles et qu'il peut automatiser grâce au système-expert.

L'expert + **S.E.DIAG** constituent ainsi une équipe efficace, rapide, économique et évolutive (Fig. 3). Qu'y a-t-il de mieux pour motiver l'expert ?

Evolutive jusqu'au sommet des connaissances en diagnostic ? Certes non, le système-expert a ses limites techniques et surtout économiques. En effet les procédures de diagnostic, à partir d'un certain degré de complexité, font intervenir ou des notions subjectives ou des grandeurs non mesurables donc elles ne sont plus automatisables. Et même en deçà de cette limite technique, l'automatisation des dernières procédures doit être complexe donc si chère qu'elle n'est plus justifiée économiquement.

De même l'expert a aussi ses limites objectives. Les dernières procédures les plus complexes demanderaient une durée d'investigation si longue que le coût d'expertise ne serait plus justifiable.

LE TELEDIAGNOSTIC ASSISTE PAR SYSTEME EXPERT

Un certain nombre de points clés de la machine à surveiller chez l'industriel sont équipés de capteurs. Les informations sont transmises à une unité locale intelligente (automate programmable, micro-ordinateur local...) qui les stocke sur un horizon coulissant de une (ou plusieurs) heure de telle sorte qu'à tout moment sont disponibles les informations relatives à la machine pendant la (ou les) dernière heure (Fig. 4).

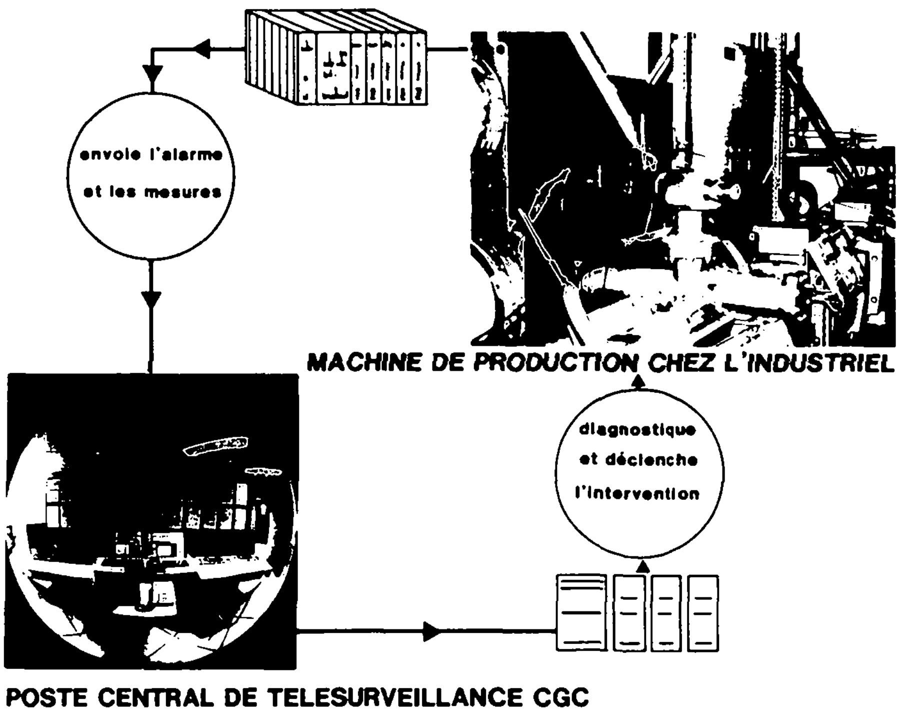


Fig. 4 : Chaîne matérielle de télédiagnostic

Dès la détection d'un défaut de fonctionnement, l'unité locale intelligente déclenche une alarme et envoie au poste central de télésurveillance les dernières informations relatives au fonctionnement de la machine pendant une (ou plusieurs) heure juste avant la détection du défaut. Dès la réception, l'ordinateur temps réel du poste central traite ces données et les transmet au système-expert de diagnostic automatique. Si l'issue est un succès, nous intervenons sur le site en fonction du résultat du diagnostic. Si c'est un échec, le paquet d'informations est envoyé chez l'expert lui-même. Ainsi il est informé et peut faire le diagnostic sans se déplacer dans la plupart des cas. S'il lui manque un certain nombre d'informations supplémentaires et seulement dans ce cas, l'expert-diagnostiqueur se déplace.

Il est à noter que dans la pratique, le choix d'une telle procédure nous permet d'assurer que dans tous les cas le télédiagnostic ne peut qu'accroître la rapidité et en voie de conséquence, l'efficacité de l'intervention (Fig 5).

<u>**Avantages du système**</u>

. **Efficacité** : le diagnostic est plus efficace car nous disposons de multiples informations sur les évènements qui précèdent le défaut de fonctionnement.

. **Rapidité** : l'exécution automatique des premières procédures de test est quasi-instantanée par rapport au déplacement du technicien de maintenance.

Dans le cas de l'échec du diagnostic automatique, le fait que l'expert peut travailler à distance augmente de manière considérable la rapidité de l'intervention.

. **Fiabilité** : implicitement, l'extension au diagnostic de défauts de fonctionnement au sens large implique une maintenance prédictive de la machine surveillée et permet de prévenir des pannes, augmentant aussi la fiabilité et la disponibilité de la machine en question.

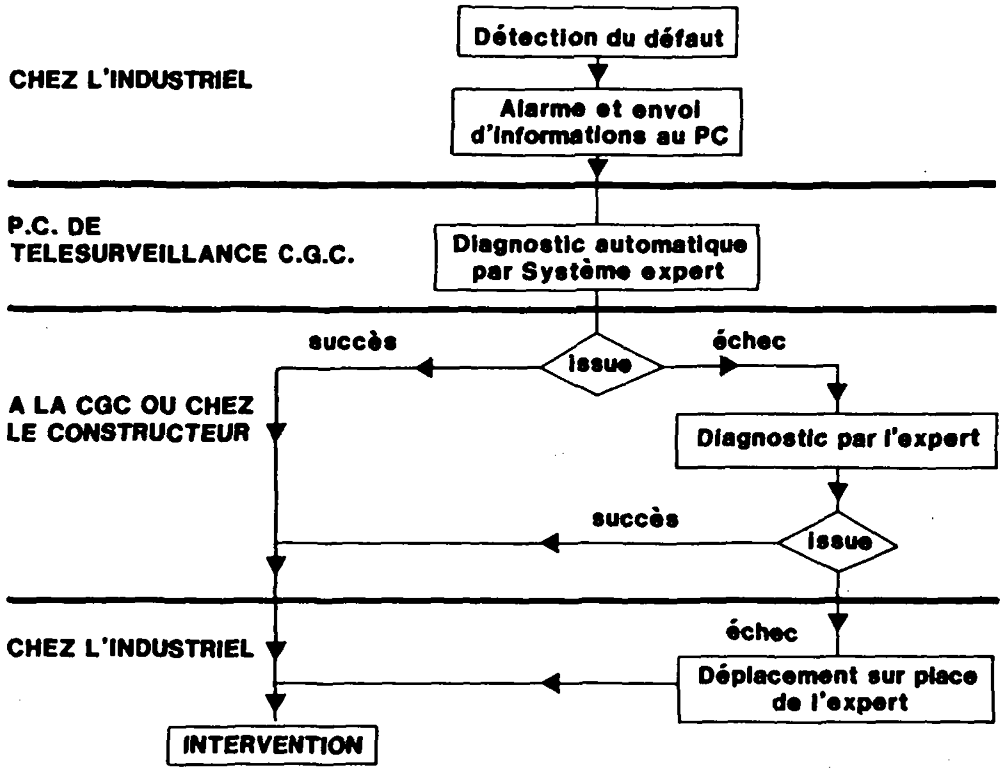


Fig. 5 : Procédure logique de télédiagnostic assisté par système-expert

. **Simplicité et confort :** le système procure à l'industriel une simplicité et un confort de manoeuvre considérables par rapport à la solution classique où chaque fois qu'une panne se déclare il doit se charger **lui-même** d'appeler le constructeur ou le dépanneur, d'attendre son arrivée etc... .

. **Evolutivité :** grâce à la structure même de l'organisation du télédiagnostic et à la nature du système expert, la chaîne globale est extrêmement évolutive.

. **Economie :** l'idée à retenir c'est que si l'on automatise 20 % des procédures de test on diagnostiquera peut-être 50 % des cas de défaut de fonctionnement. Grâce à la télétransmission, l'expert peut régler sans se déplacer 30 % des cas et ainsi on économise les frais de déplacement de l'expert dans 80 % des cas.

L'autre économie considérable du système résulte du fait que l'on dispose dans 80 % des cas du résultat du diagnostic avant le déplacement du technicien de maintenance permettant ainsi d'envoyer sur les lieux le personnel et les matériels appropriés... si besoin est (en effet, pourquoi y envoyer un technicien pour remplacer un plomb ou débloquer une vanne ?).

Inconvénients et limites du système

. La dimension temporelle des évèvements précédant la détection du défaut n'est pas intégrée dans le système-expert lui-même alors qu'elle est riche en informations utiles au diagnostic. Nous avons dû y remédier partiellement en créant des interfaces-traductrices de mesures numériques en connaissances proportionnelles. Et ces interfaces sont encore assez lourdes à mettre en oeuvre.

. Le système est mal adapté pour le diagnostic automatique des pannes qui surviennent **brutalement** sans dérive d'aucun paramètre mesuré.

CONCLUSION

C'est en réfléchissant sur la maintenance d'équipements industriels et la pratique actuelle du diagnostic technique que nous sommes conduits à penser qu'il y a possibilité d'en améliorer la rapidité et l'efficacité grâce à des outils modernes de télétransmission, sous réserve que l'on dispose de logiciels d'analyse performants.

La technique des systèmes-experts semble apporter des solutions prometteuses à ce type de problème et nous avons cherché à la mettre en oeuvre en l'intégrant dans un environnement industriel existant. Ce qui nous a conduit à imaginer cette procédure automatique de **"télédiagnostic assisté par ordinateur"**, mise au point pour une installation thermique. Cependant, les concepts généraux développés au cours de cette contribution, nous permettent de penser que certaines idées peuvent être tout à fait transposables à d'autres domaines d'activité : celui de l'eau par exemple.

Quant à l'évolution possible de ces techniques d'ici l'an 2000, disons tout simplement qu'elle risque d'être assez imprévisible dans la mesure où, aujourd'hui, le diagnostic technique reste la préoccupation de nombreux laboratoires dont les directions d'investigation sont assez différentes les unes des autres.

SESSION 3

SEANCE 3

Chairman
Président Dr. M. SCHALEKAMP

- The Implementation of Information Technology to the year 2000 - A Realistic Approach

  Mise en oeuvre de la technologie de l'information jusqu'à l'an 2000 - une approache réaliste

  D. Beale

- Electronic Information for Sanitary and Environmental Engineers - 1965-1987 and beyond

  Information électronique pour ingénieurs sanitaires et environnementaux - période 1965-1987 et au-delà

  J. Robinson, Kurt M. Keeley

- Computing - Not Yet Half Way There

  Calcul informatique - pas encore à mi-chemin

  N. Cullen

Discussion

THE IMPLEMENTATION OF INFORMATION TECHNOLOGY TO THE YEAR 2000 - A REALISTIC APPROACH

D. Beal

Wessex Water Authority, Wessex House, Bristol BS2 0JQ, England

ABSTRACT

The paper addresses two important issues in Information Technology (IT) in its application to the management of water networks. The first of these is the integration of real-time data with supporting static data from a different source. The second is the need to ensure that developments in IT meet the needs of the organisation and its objectives.

Recent progress in IT has gone some way to achieving the above goals. Networking and integration of computers, along with database techniques, exemplify this; there is now also a much better understanding of the interaction between computer and operators. The paper illustrates the application of such techniques by reference to an innovative approach which is currently under trial in the integrated management of water supply. This approach brings together data from different sources, using a relational database for manipulation. This modular approach has a number of advantages, notably its ability to build on existing systems and its compatibility with future developments.

KEYWORDS

Information; telemetry; telecommunications; database; management; integration; man/machine interface.

"WE ARE DROWNING IN INFORMATION BUT STARVED OF KNOWLEDGE"

INTRODUCTION

The commitment of resources in information technology in the United Kingdom water industry continues to increase in line with world-wide trends.

The successful information systems are generally to be found in easily quantifiable, well-ordered activities. The operating rules are definable and the basic information reliably measured. Hence the widespread and effective use of computers for accounting, stocktaking, record keeping. The primary activities of the water industry, however, are carried out in a real world where there is environmental uncertainty, unpredictable events and limited detailed knowledge of the assets being managed. This paper describes an approach to practical integration of the varied sources of information in a way that utilizes past investments and recognises future uncertainty to meet the needs of the water industry now and in the years to come.

BACKGROUND - THE CURRENT POSITION

Throughout the world, the water industry is a major business with its assets and customers dispersed geographically. In the United Kingdom, as elsewhere, recent years have seen considerable agglomeration in the bodies responsible for management of the water cycle.

During the last decade a number of factors have led to a demand for more and more information in a flexible form. These factors include:

- need for more effective allocation of limited resources, both finance and manpower;
- increasingly exacting customer standards of service;
- customer expectations exceed the availability of resources and the willingness to pay;
- greater financial regulation by Central Government;
- greater public accountability;
- changing business objectives are often required to meet political changes.

These changes have placed significant pressure on managers to improve the service to the customers while minimising both the impact of changes and any consequent increase in costs.

Because of these changes, the water industry today finds itself in a position where more information is required than ever before about what our assets are, where they are, what condition they are in and how they are performing. Moreover, there is every reason to believe that this trend will continue, with demands on information likely to increase into the next century.

In order to handle these demands, it is important that the best possible use is made by the water industry of the available information technology.

WHAT TECHNIQUES ARE AVAILABLE ?

Many of the tools of information technology which can assist in this process - they might be viewed as pieces of a jig-saw - are already available and it is appropriate to review them briefly here.

Telemetry, the collection of data in real time, is now accepted as making a major contribution to effective management of water networks, providing the ability to monitor installations remotely and also, increasingly, to operate the network.

Modern digital telecommunications, on which telemetry is reliant, remove the spatial constraints on access to all forms of data. Information can be made available where it is required, regardless of the location of either source or user.

Database techniques offer the rapid storage and retrieval of information about the assets. Using this approach, redundancy of data can be reduced and inconsistency eliminated. The same data can be shared between different users but each has access to the data that they need.

Traditionally, telemetry systems have developed separately from other management information systems and the system boundaries have not been easy to break down. The merging of real-time data with other computer-based information is logically necessary when operational management requirements are defined.

Ideally, new data requirements could be taken on board without affecting existing applications. Equally, not all the benefits can be achieved without a considerable investment of resources, particularly if data from diverse sources is involved.

Current computing capabilities have considerably facilitated the use of mathematical techniques to model network performance. Supply network analysis is now an accepted planning tool and is increasingly being applied in real-time as part of a decision support system. The same is true of minimising pumping costs by mathematical modelling.

Digital mapping techniques are now available which combine the power of database with the provision of graphical capabilities. An organisation's assets can thus be viewed in a readily assimilated fashion while the associated data can be reviewed, aggregated, summed or sorted as required by the user. Such data might include pipe sizes and materials but could also relate to the condition of the assets, for example, recording the position of known defects. As well as providing static network data, digital mapping can also be used to record bursts or complaints - indeed, anything which has a geographical basis.

The introduction of windowing on computer displays to show on one screen the results of many applications can greatly enhance the span of data available.

WHAT HAS BEEN THE EFFECT OF THE TECHNIQUES OF IT ON THE WATER INDUSTRY ?

The shape of the standard management structure is changing and the use of information technology is hastening the change. The size of the workforce at the lower level of the organisation has been greatly reduced as a result of improved productivity, automation, etc. This reduction has been met partly at the expense of some increase in lower/middle managers and support staff. Much of their time is spent in collating and interpreting data for use by senior management. This can be labour intensive but information technology is progressively enabling this manual activity to be carried out automatically. Decision makers, themselves, are potentially able to receive information which has been analysed, interpreted and presented by information systems to meet their own requirements. Without integration, the capabilities of IT to assist in meeting objectives will be beneficial but limited.

The wide range of separate systems that have been developed in almost all organisations make it difficult for a manager, particularly one with operational responsibilities, to take an overall view and to react to changing circumstances within the often short time available.

The establishment of a good communication system removes many of the constraints which hinder rationalising an organisation. It also provides the potential for decisions to be taken relating to the most cost effective means of providing central services. However, it must be said that where services are centralised a greater emphasis must be placed on the effectiveness of persons providing the service - new technology will not do their job for them.

Day-to-day operations have, in the past, been operated with information which is at best incomplete, at worst non-existent: decisions which were made on the spur of the moment usually had to rely on subjective judgement because the necessary information was not readily accessible. Indeed, operation was of a 'reactive' nature - if no complaints were received, it was assumed that all was well. In relation to planning, the information the manager requires may be available, but in a form which calls for considerable work in collection and collation, a task for which scarce resources may not be available. At the strategic level, the approach leads to inflexibility and the consequent difficulties when the organisation or its objectives change.

This illustrates a key facet of data integration: that its achievement would bring benefits at all levels of the organisation, from day-to-day operations to the strategic decisions taken by senior management.

HOW CAN EFFECTIVE INTEGRATION BE ACHIEVED ?

One possible approach would be to make a "fresh start", but this is clearly not practicable in the current cost-constrained environment. More realistically, the problem can be analysed as three separate but related issues. Firstly, data from a number of diverse sources - for example, static data from digital mapping and dynamic data from telemetry - must be brought together. Secondly, a means must be provided of collecting, manipulating and presenting whatever parts of this integrated data are required. Finally, because the volume of data is potentially bewildering, a man-machine interface is needed to guide the user to what he requires. Realistic solutions to all these three have become commercially available within recent years.

In most organisations, the need for an integrated presentation of information from diverse sources is achieved by staff interpreting data for the managers using devices such as personal computers for collating and analysing information. In practice, there is a significant but often hidden overhead cost.

The physical integration of different systems is a technical problem which manufacturers now realise it is in their interests to pursue. As a consequence, practical communication links between separate computer systems such as Open Systems Interconnect and SNA-Gateway are providing users with the means of systems "talking to" each other in a way that would have been impossible a few years ago. The user of a terminal need no longer be tied to a single computer but, using these techniques, can access different systems as appropriate.

Database technology now provides the means of handling and accessing large volumes of data. In particular, relational databases are now acknowledged as having a number of advantages for the user. These include basic simplicity for the user, a rigorous mathematical approach and the absence of an artificial data structure giving simplified access to the data. The size of that relational database must, however, be constrained to minimize cost and complexity.

Finally - and perhaps of greatest importance to the user - access to the data must be provided in such a way that, even in an emergency, it is possible to reach the required data rapidly and efficiently through a single display screen. The user must be guided through the available options and conventionally now this is achieved by, for example, screen menus which enable easy selection of options without use of the keyboard.

THE REQUIREMENTS OF AN INTEGRATED SYSTEM

The principal features of a typical truly integrated system are thus:-

(a) Interfacing many systems such as telemetry, water quality and financial information, independent of their supplier, to collect the information in one location, running on a single workstation (essentially a mini-computer in its own right);

(b) Using a relational database with its inherent advantages of data manipulation to integrate the information;

(c) Presenting data to the user through proven man-machine interface (MMI) technology, using modelling capabilities where required, in order that different facets of the data can be accessed simply and rapidly;

(d) Modular development and implementation, giving forward compatibility with other current and future developments, thereby building on the investment already made in systems as much as possible;

(e) Available to all levels in the organisation.

WHY A PROTOTYPE ?

The main arguments against such a proposal are, however, that a wholesale commitment would require large investments of resources and lengthy timescales while there is a danger, however slight, that not all the benefits would accrue. Wessex Water is currently involved in the development of an integrated system such as the one described above but is aware of the need to keep costs to a level which provides an acceptable return on investment. Consequently, a prototype development has been undertaken. The prototype offers four principal benefits:

(a) Limited and controlled initial expenditure;

(b) An easily demonstrable system which will encourage critical comment from users;

(c) The ability to address more effectively the feasibility of such a system and to verify potential benefits;

(d) Illustration of possibilities for a full system.

The prototype demonstrates the way in which such integration may be accomplished and the way in which it might work. The system required will be acceptable to users who are generally non-computer personnel. Consequently, a highly user-friendly man-machine interface has been provided as a pre-requisite to a successful system. In order to gain full appreciation of an integrated water management system a site has been selected for prototype implementation which will maximise the effectiveness of the demonstration and provide the necessary feedback from users.

SOURCES OF INFORMATION

The prototype system will necessarily connect into existing hardware elements. This is essential in order to take full advantage of the investment made by Wessex Water in telemetry and in-house computing facilities. In particular, the prototype will be required to communicate with the following:

(a) Network supply data collected by telemetry and data loggers;

(b) Mainframe system containing financial and other management information;

(c) River basin, hydrological and water quality data from a number of mini-computers;

(d) Meteorological office weather radar data.

A deliberate attempt was made to use an extremely diverse range of systems to feed information into the workstation.

DATA MANIPULATION FACILITIES

A key element of the prototype will be the data manipulation facilities provided. These will be required to demonstrate how various data sources may be combined to illustrate aspects of water management, including:

(a) Financial control;

(b) Manpower and productivity;

(c) Achievements against standards of service;

(d) Forecasting and live monitoring of supply networks and river basins.

The required scheme is shown in Appendix 1. The use of a large multi-window screen that allows a number of displays to be simultaneously active is typically shown in Appendix 2.

The man/machine interface (MMI) design will support operation by ensuring that the minimum of operator intervention is necessary for tasks to be completed rapidly and accurately. Where operator interactions are required, these are accomplished simply and consistently throughout the system. The design of the MMI has centred on four main factors:

(a) operator/user;

(b) operational environment;

(c) equipment selected;

(d) project timescales.

It can be seen that the prototype, although its scope is limited in some respects, has much of the functionality of a complete system and will allow a realistic assessment before further modular expansion takes place.

Looking to the future, the very nature of such a system means that it can ultimately incorporate not only existing known developments but also those which are currently at the experimental stage. For example, Wessex and others in the UK water industry are currently co-operating in the development of an expert system to assist in the management of the water distribution network during emergencies. In future years, this and other expert systems might play a role in operational management and is a development which can be incorporated as and when required.

THE WATER MANAGEMENT SYSTEM IN THE YEAR 2000

The current obstacles between a manager and the information within his organisation will progressively break down as a result of the massive investment being made world wide into research and development in this area. The system will be organised to present information and to respond to demands in a way which more closely matches the way human beings think and act. For example, instead of the clumsiness of a typewriter-like keyboard, the system should be able to respond to speech. More information will be presented after the system has carried out deductions to reach conclusions. This substitution of computing power for some of the tasks now carried out by the human brain requires much larger computer processing capacity which, in the year 2,000, should be available at relatively low cost and be of small physical size. Two hardware developments that are contributing towards the continuous improvement in performance are parallel processing and optical disks.

The integration of the systems which feed data into the workstation used by the "manager" will be significantly easier as either real international standards emerge or that issue is resolved by utilizing the higher levels of computer power. Similarly, access to the information will not be restricted to the office or constrained by cabled connections. The manager will be able to use the system without being forced to make decisions in particular locations. As operational circumstances demand human judgment, then the information to make that judgment will be available in the car, the office or the home.

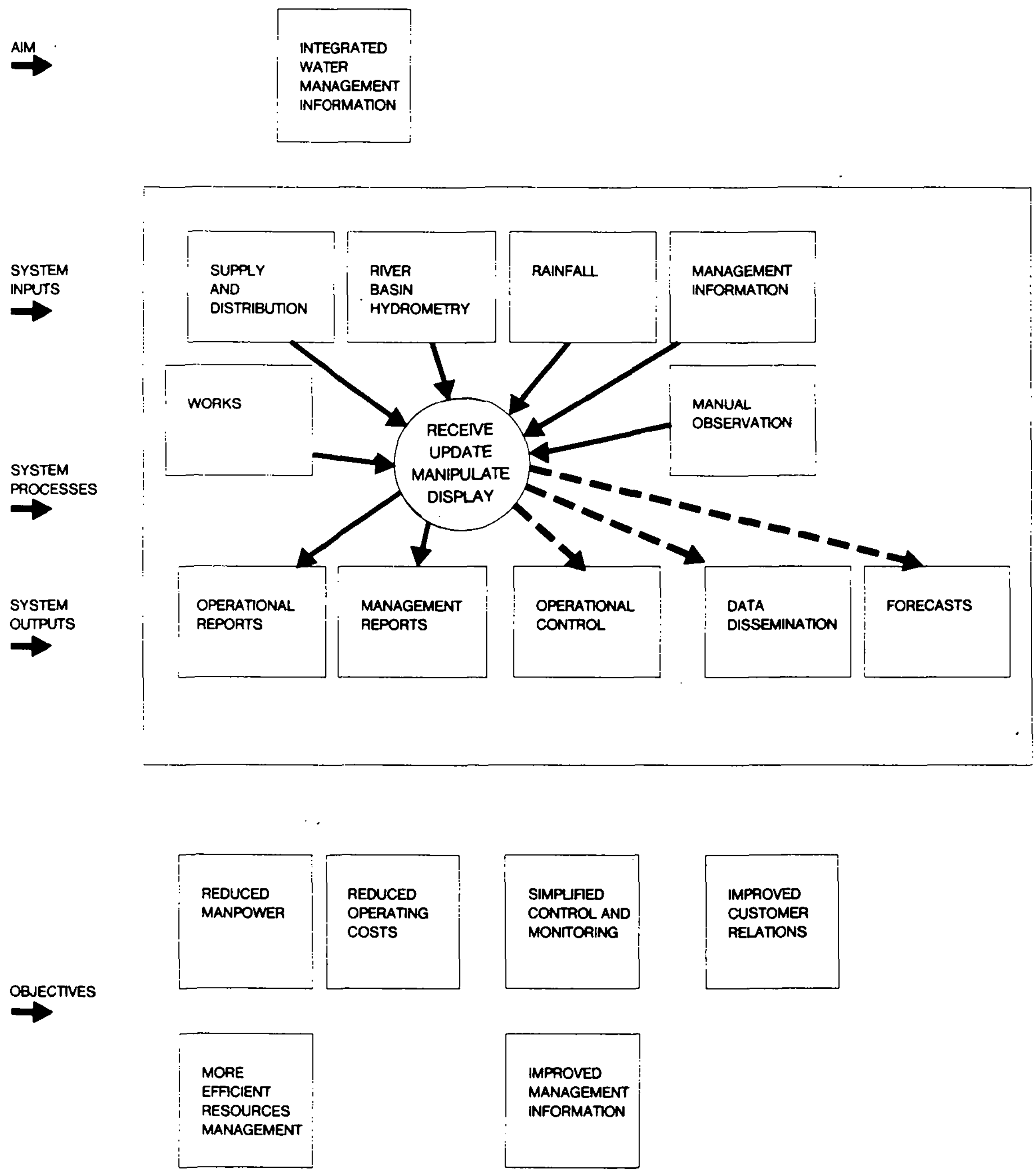
CONCLUSION

The prototype system provides "high level" management support primarily for operational managers. The concept recognises that there is no definitive answer to management information requirements even for apparently identical organisations or for those who have similar objectives. Every manager, and the team he leads, in reality has an idiosyncratic approach to the information he requires and how it is to be presented. Hence, the failure of standard system solutions to satisfactorily meet common industry requirements and the limited value of apparently objective data analysis exercises.

The "Water Management System" is designed to evolve to take advantage of technology developments as they become credible and to adapt to the inevitably changing management information requirements of the future.

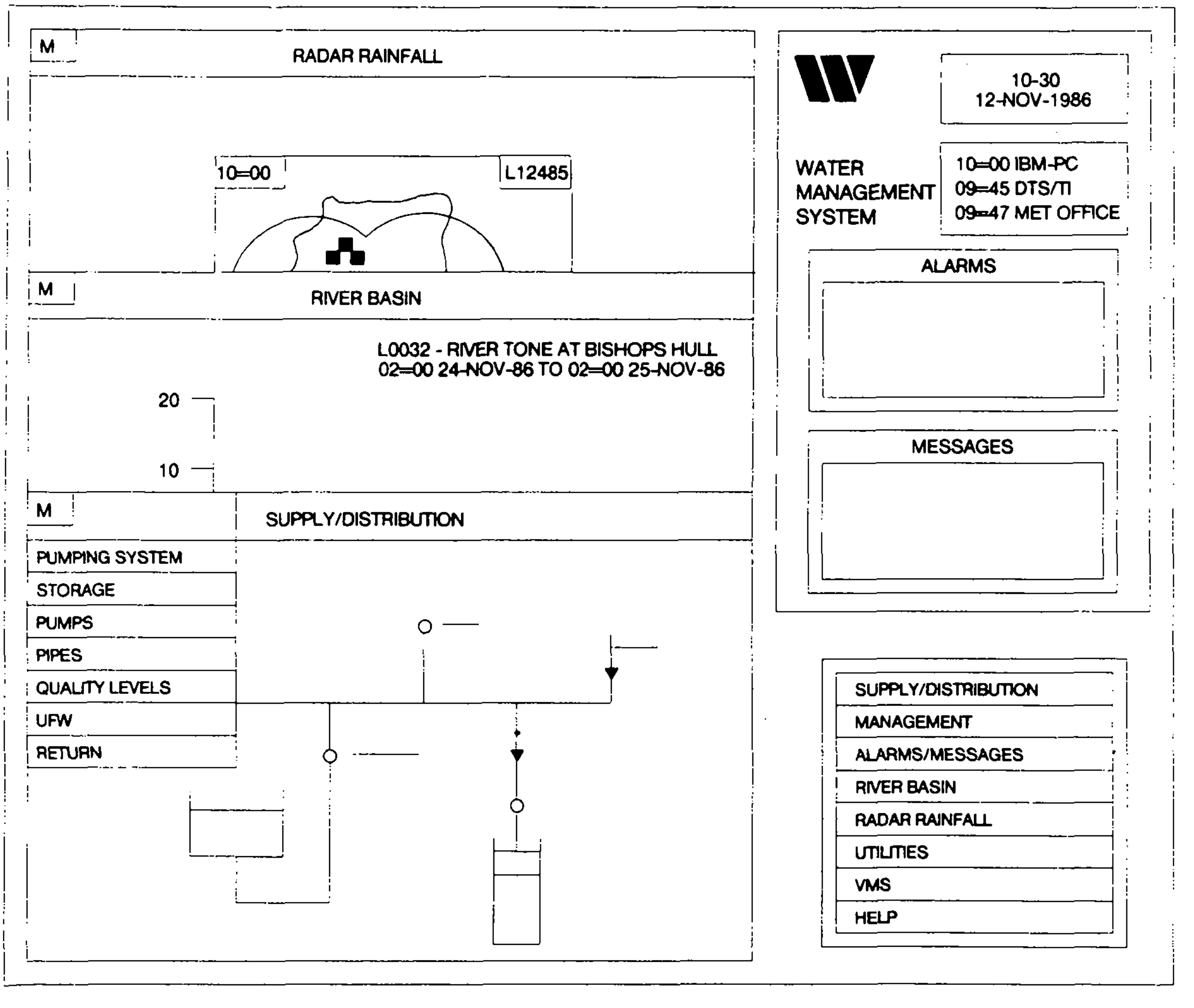
Appendix 1

OVERALL CONCEPT



Appendix 2

EXAMPLE SCREEN



ELECTRONIC INFORMATION FOR SANITARY AND ENVIRONMENTAL ENGINEERS-1965-1987 AND BEYOND

*Kurt M. Keeley, **Jack H. Robinson

*American Water Works Association, 6666 West Quincy Ave., Denver, Colorado 80235 USA
**Black & Veatch, 1500 Meadow Parkway, P.O. Box 8405
Kansas City, Missouri 64114 USA

ABSTRACT

Bibliographic online information retrieval started in the 1965-1970 timeframe. Databases covering environmental engineering started to appear in the 1970's. The number of databases has grown from just 2-3 databases available in the late 1960's to over 3,000 available in 1987. The databases are available from over 100 suppliers worldwide. These bibliographic databases can save engineers and water professionals significant amounts of time and they are cost effective to use. In the 1980's there are other kinds of databases becoming widely available such as numeric, directory, and full-text.

KEYWORDS

Online information retrieval; databases; information processing; scientific and technical information.

I. INTRODUCTION

In 1987 professionals in environmental engineering use significant amounts of information to complete their tasks. This information comes from technical reports, standards, books, journals and magazines, professional contacts, and many more sources. In sanitary engineering much of this information is becoming computerized at a very rapid rate. This paper will review the historical development of this computerization effort since 1965 and explain the costs, economies, types of databases, and trends involved.

Information is a large industry just as manufacturing, mining, or agriculture. John Naisbitt in his 1982 best selling book MEGATRENDS notes that the US has moved from an industrial society to an information society. This move started as early as 1956 and 1957. He notes there appears to be a shift from industrial workers such as machinists, welders, jig makers to professional and clerical workers that create, process and distribute information.

> *"Professional workers are almost all information workers-- lawyers, engineers, computer programmers, systems analysts, doctors, architects, accountants, librarians, newspaper reporters, social workers, nurses, and clergy." (Naisbitt, MEGATRENDS, p. 5)*

You as technical and professional people will be assisted in solving your problems correctly and quickly if you have timely and reliable information. If there is too much information you may get bogged down. Then you need to sift out what is useful. Information technology and information processing help bring order to this over-abundance of information. Online databases and information brokers are a 4 billion dollar a-year business in the United States. In 1970 there were less than 50 databases and now there are over 3000!

As background to how databases grew in popularity in 17 short years, we must look at how the processing of printed information has changed. We must also look at the relationship of various players in the "information cycle."

Until the 1970's information to be printed was typeset using various mechanical and electro-mechanical methods. Indexers and abstractors who received this information then created another print product that was published as a book. This was then purchased by the information agency (libraries) and used to locate information.

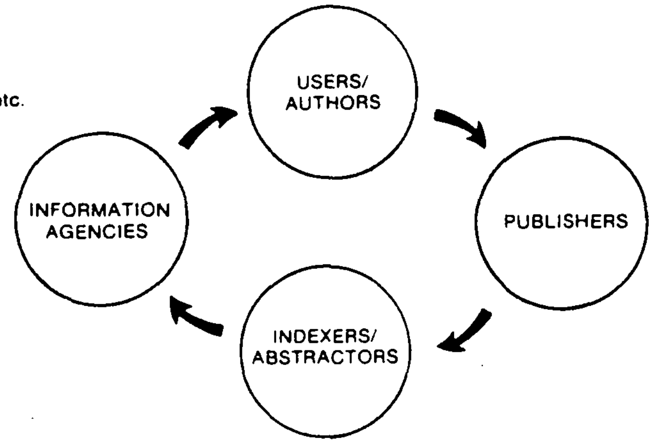
After 1970 one product or by-product of creating this index was the same data stored in machine readable language on a diskette or magnetic tape. This data could then be searched and manipulated by running a software program against it to create lists of titles or authors or subjects or all three. This gave rise to "computerized vendors" who collect, store and market these electronic products. (refer to fig. 1)

Figure 1

THE INFORMATION CYCLE

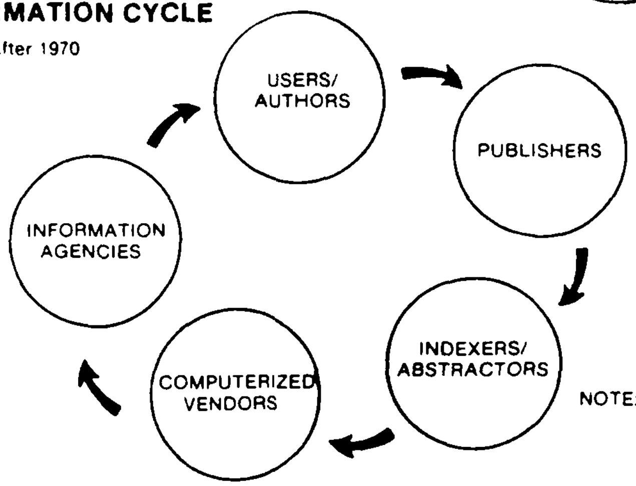
Until 1970

NOTE: The traditional forms of information on paper and print based medium such as books, magazines, journals, etc.



THE INFORMATION CYCLE

After 1970



NOTE: Alternate format is electronic media. The products exist in many forms: paper, magnetic tape, film, hard discs, etc.

Figure 2 **Database Services (1965-1979)**

1965 → 1969

USER: **MAJOR GOVERNMENT AGENCIES**
- NASA
- DOD
- AEC
- HEW

1970 → 1974

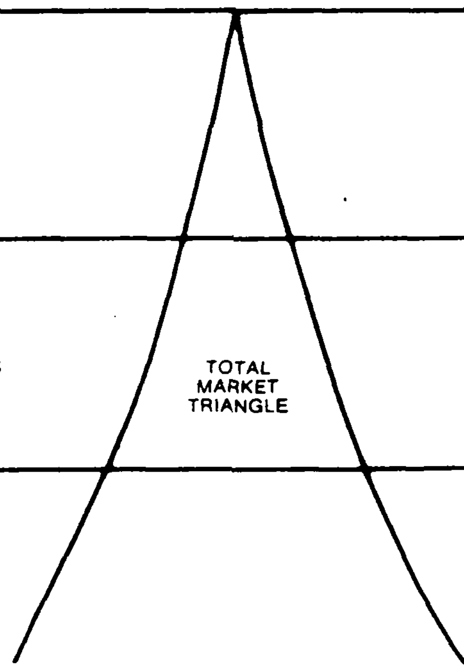
USERS: **INDUSTRIAL AND ACADEMIC INSTITUTIONS**
- UNIVERSITY AND NON-PROFITS
- ENGINEERING AND MANUFACTURING
- STATE AND LOCAL GOVERNMENT AGENCIES

DATA BASES: 15-20
COST PER SEARCH: $10-$50

1975 → 1979

USERS: **INDIVIDUAL PROFESSIONALS**
- CONSULTANTS
- PROFESSIONALS
- CITIZENS

DATA BASES: 50-100
COST PER SEARCH: $1-$5



Other subject fields have computerized their information for rapid recall sooner than those in the field of sanitary engineering. These are medicine, law, chemistry, education (elementary & secondary), and business. Sanitary engineering was grouped in the 1970's in the broad category of civil engineering. In the late 1970's and early 1980's more subject databases became available on sanitary engineering. For example:

Year	*Database*	*Producer*	*Country*
1979	*AQUACULTURE*	*NOAA*	*US*
1981 (February)	*AQUALINE*	*WRC*	*UK*
1981 (December)	*WATER RESOURCES ABSTRACTS*	*Dept. Int.*	*US*
1982 (September)	*WATERNET*	*AWWA*	*US*

Many of these subject databases were under development and operated in a test mode 2-4 years prior to being made available to the public. This is true for AWWA's WATERNET which started in 1980 and became available worldwide in 1982.

Part of this trend of electronic databases is characterized by charging for their use. In this new "information economy" that Nesbitt talks about we see that information is no longer free. Information is now broken up into smaller units and priced accordingly. Prior to this new move to pricing that matured from 1972-1980 information users were accustomed to paying once for an entire information source, eg a book. Now people pay for references to books, abstracts to chapters of books, and complete text of books or reports. These charges are in addition to the telephone charges to make the connection to the computer, and some charge to cover purchasing the computer hardware needed for the activity. The price of this hardware could be amortized over 2-3 years. Also, training, reference books, or technical manuals are extra charges for information.

Even considering these five elements of cost for information to the sanitary engineer, this process is still a cost-effective way to find information and have it delivered electronically.

Books and electronic databases are closely related in how they are produced. Books are being printed using electronics and computer technology. In some cases, we are seeing electronic by-products, such as computer databases for sanitary engineers being sold in addition to the book. In many cases these databases contain references to the printed book that is published by the same publisher.

In addition to technology, databases are widely available today because of the vast amount of information being published. For instance barely 10 years ago, (1977) there were over 25,000 book titles printed in the U.S.; in 1985 there were over 41,000 titles printed not including paperbacks. More importantly in the scientific and technical literature where we locate environmental engineering literature, we see significant changes. Note what Toffler had to say in 1970 about scientific technical reports.

> ***"Today ... the number of scientific journals and articles is doubling...about every fifteen years...the United States government alone generates 100,000 reports each year, plus 450,000 articles, books and papers." (Toffler, 1970-FUTURE SHOCK)***

Nesbitt in MEGATRENDS (1982) believes the sheer volume of information is even more startling:

- ***Between 6,000 and 7,000 scientific articles are published each day.***
- ***Scientific and technical information now increases 13 per cent per year, which means it doubles every 5.5 years.***
- ***This rate may jump to 40 % per year because of new, more powerful information systems and an increasing population of scientists. If this happens data will double every twenty months.***
- ***By 1985 the volume of information will be somewhere between four and seven times what it was only a few years earlier.***

The advances in electronic publishing and computerization together with the vast quantities of printed information that needed to be stored and located led to "computerized indexes or databases." They started emerging commercially in the 1970's.

II. GROWTH OF DATABASES SINCE 1965

The growth of databases in the last two decades has been spectacular. In 1965, there were just a handful of databases, and now 22 years later there are over 3,000! How did this happen?

(refer to fig. 2)

Starting in the early 1960's the US government was seeking ways to better organize its technical report information. Not only were more technical reports being written during the early era of space research (1960-1970), but also the ways to handle this information were being changed. Quantities of reports became so great that scientists started using computers to track and identify them. Early efforts were made at the Oak Ridge National Laboratories and other government laboratories to index and retrieve information by computer. Three distinct eras were apparent. These eras are based on the number of databases available, the cost per search, and user agencies.

1965-1970
The first groups of databases were designed and used primarily by large governmental agencies. These include the Department of Defense, National Aeronautics and Space Administration (NASA), the Atomic Energy Commission (AEC), and the Department of Health, Education and Welfare (HEW). Databases for these agencies were developed during the 1965-1969 timeframe. A typical single search done by the computer would cost $1000. Searching was very limited to the 2-4 databases mentioned, per search costs were very high, and access was restricted. There were no civil or sanitary engineering databases at that time.

1970-1976
The next era is marked by increasing number of databases, falling prices for the per search cost and more groups using databases. By this time the databases were used primarily by government. New people now beginning to use the databases were large businesses and corporations, research centers, universities and colleges, In the early 1970's there were approximately 20 subject databases available and the cost of a database search or query cost $50-$100. By mid-decade there were nearly 40 databases available and many more people were using this method of information gathering. In this early era there were approximately 3-5 databases:

Examples:

SciSearch-Institute for Scientific Information, Philadelphia, PA
Compendex-Engineering Information, Inc., New York, NY
Pollution Abstracts-Cambridge Scientific Abstracts, Bethesda, MD
NTIS-National Technical Information Service, US Dept of Commerce, Springfield, VA
Inspec-Institution of Electrical Engineers, London, England

1977-1980
By 1977 the database picture was changing even more rapidly. There were 1-2 new databases becoming available every month and the total number of computerized databases numbered 100-200. These represented nearly 70-80 million pieces of information or abstracts. Users now extended to consulting engineers, state and local governments, and citizens. The cost of a search was a low as $1 and went to $5 for very simple questions. Of course there was no upper limit for a search cost. There were approximately five databases dealing with civil and sanitary engineering:

Examples:

COMPENDEX-Engineering Sciences, Inc., New York, NY
Oceanic Abstracts-Cambridge Scientific Abstracts, Bethesda, MD
Aquatic Science and Fisheries Abstracts-National Oceanic and Atmospheric Administration
NTIS-US Dept. Commerce, Springfield, VA
SciSearch-Institute for Scientific Information, Philadelphia, PA

To summarize, from 1980 to the present the number of databases has exploded well beyond 200. In the 1970's, there used to be 2-3 database vendors or brokers of databases, now there are nearly 100.

More importantly, today from just one computer vendor there are over fifteen databases covering the fields of energy and environment and these represent some 22 million articles. Also from the same computer vendor there are another 25 databases on the topics of science and technology. These represent another 19 million articles. Compare these forty databases covering 40 million articles with the one or two that were available in the early 1970's. These contained barely 200,000 references on environmental engineering or science.

Not only are databases increasing in the total number but also there are more kinds to choose from.

III. TYPES OF DATABASES IN THE 1970'S AND 1980'S

BIBLIOGRAPHIC DATABASES

To understand the growth of databases and their possible use in your field it is important to realize how they are constructed and explore the different kinds. Databases since the mid 1960's and thru the early 1980's were primarily "bibliographic databases." This means they contained references to original documents in article or technical report form. Typical items listed include author, article title, date, journal name, keywords that describe the main points, and a 250 word abstract of the article. Bibliographic databases far outnumber the other kinds. Whole articles are not included in bibliographic databases. Figure 3 includes a sample from a bibliographic database.

Fig. 3-Sample Abstract
Bibliographic Database

009009
CO000075
Conf Proc
De Azebado, Jose M.
Practical Considerations for Designing Small Water
Treatment Plants
--Espanol--Consideraciones Practicas Sobre El Proyecto
de Plantas de Tratamiento de Agua de Pequeno Porte
Expo-AIDIS '82 XVI Congreso Interamericano de Ingenieria
Sanitaria y Ambiental
11 p
English
AWWA
August 1-6, 1982
Panama
17 references
Small Water Systems, Design

When designing small water treatment plants the designer needs to keep these important ideas in mind: know the level of training of the normal operators, even in small plants design a margin of safety for operating levels; know the ranges of raw water quality in various seasons; there are may basic texts on basic slow filtration that can be consulted; rapid sand filters are available in Latin America and should be check out; disinfection is essential and chlorine is the most commonly used; keep in mind the Russian KO-1 filters as an alternative to conventional treatment; check the World Health Organization for standardized small projects and plans; check also the package plants available.

El autor repasa varias temas que tiene que tomar en cuenta para disenar una planta de tratamiento simple. Por ejemplo tiene que tomar en cuenta la capacidad y educacion de los operadores; siempre conviene tener un margen de seguridad, aunque sea pequeno; la falta de conocimeinto de la calidad del agua bruta ha sido uno de los errores mas comunes; hay varios manuales sobre diseno de filtros lentos por la OMS; no se olvide de los filtros rusos KO-1; no se olvida de las normas hechas por los rusos, la India, y las de la Argentina y Brasil.

COMPLETE TEXT DATABASES

In the mid 1980's (1985) a new kind of database was introduced called a "complete text database." Here the entire or full narrative text of a journal article or source publication is stored in the computer. It can be searched and printed out easily. Full text databases are growing in popularity but they have some drawbacks. For instance charts, tables, figures, photos and drawings may not be included. Examples of these full text databases are below with per article price:

TITLE	*COST PER ARTICLE*
MAGAZINE INDEX (#47)	
magazine articles	***$3.50***
TRADE INDUSTRY INDEX (#148)	
trade journals	***$3.50***
HARVARD BUSINESS REVIEW (#122)	
journal articles	***$7.50***
CLAIMS/CITATION (#220-222)	
patents	***$20.00***
ARTHUR D. LITTLE ONLINE STUDIES (#192)	
forecasts, planning reports	***$100.00***
ICC BRITISH COMPANY (#562)	
financial datasheets	***$8.00***

Complete text databases generally are more expensive to use if you consider the cost of printing the document. They do offer immediate access to the article at your terminal but at a premium cost.

NUMERIC DATABASES
Early in the 1980's a third type of database began to appear and it is called "numeric." Here the information consists of numeric statistics, tables, and financial data. Some tabular information can be rearranged and merged with other pieces of data. Few engineering databases to date are numeric. Examples of this type of database are:

DONNELLEY DEMOGRAPHICS
census data, projections and estimates

MEDIA GENERAL
company financial and trading information

TRINET ESTABLISHMENT
current address and financial and marketing information on companies with more than 20 employees

STANDARD & POORS REGISTER-CORPORATE
corporate description of publicly held companies

TRADEMARKSCAN
list of trademarks on file

Another example of a numeric database is AWWA's *"WATER INDUSTRY DATABASE."* In 1985 AWWA revised a previously published statistical book into an online computerized numeric database. The Association sent out a very detailed three part, 20 page questionnaire to 600 of the largest water utilities in the United States and to the largest Canadian water utilities. Responses were received from 430 of the 600 US utilities and 75 of the Canadian utilities. In the US these utilities served over 104 million people and over 5 million Canadian people were served.

Results from these questionnaires were keyed into a microcomputer, a DIGITAL MicroVAX, located at AWWA headquarters. The software permitted questions to be answered and queries made on over 350 fields of data. *WATERNET* by contrast has 20-25 fields. In addition to having online query capability, the data was used to produce a book containing 22 reports covering nearly 300 pages.

DIRECTORY/DICTIONARY DATABASE
Another type of information database is the directory/dictionary database. This consists of names and complete addresses along with phone numbers and telex numbers. An example would be to have the IWSA directory roster on a computer with complete member information. Another example would be the telephone book of your city. Examples of this type of database include:

AMERICAN MEN & WOMEN OF SCIENCE
BOOKS IN PRINT
BUSINESS SOFTWARE DATABASE
CHEMNAME
CONSUMER DRUG INFORMATION
ICC BRITISH COMPANY DIRECTORY
MARQUIS WHO'S WHO

IV. TRENDS FOR THE 1980'S AND 1990'S

Some of the trends for the 1980's are already in place and well established. These will lead the way to some new developments in the 1990's that will affect the processing of information. Here are some concepts to consider.

A. Information is a commodity similar to other products and it has value. Some information has been given away but it is now being sold. Information will go up or down in price based on demand. Just as some print products (books, magazines, journals) do not sell well, so is the case for databases. Databases may be retired or withdrawn from the marketplace based on economics or other factors.

B. There continues to be a strong connection between print publications and electronic information. One usually derives from the other. The same information can be sold and re-sold various times in print or electronic formats.

C. Bibliographic databases still occupy the majority of the scientific market place. Document delivery goes hand in hand with bibliographic databases. Document delivery means transmitting or delivering the full document to the requestor. This can be done electronically or by other traditional delivery means.

D. Service centers or information centers that supply information will continue to do so at a cost. If speed of delivery of the information is important the price will rise.

E. There is a wide gap between US supplied information producers (in any format) and lesser developed countries. European countries are moving to market some databases that the US did five years ago. Developing countries cannot afford to pay for much of this electronic information. Yet, they should be one of the biggest users of it.

F. The key to understanding and using online searching effectively is education and training. The trend we see is to teach online searching at high school levels. This is now taking place in the United States and Canada on a limited basis. Many online vendors are offering special educational rates for high schools.

G. Complete databases are now available on CD Rom (Compact Disk Read Only Memory). They are priced in the $1000-$5000 range. They can easily be adapted to personal computers.

V. SUMMARY AND CONCLUSIONS

Information for sanitary engineers is widely available but not always at the right place in the appropriate format. Professional societies, research institutes and profit companies are trying to make the needed information available in the appropriate format to engineers so they can perform their tasks. AWWA for instance has taken its bibliographic database, ***WATERNET***, and made it available on four continents in 36 countries of the world. The numeric database, WIDB, is not yet available online to requestors. But there is a print version that is "downloaded" from this database.

In the broader picture there are economies of scale from the computer development over the last 2 decades that enable civil and sanitary engineers to bring electronic desk-top publishing into their offices and work.

Microcomputers are reaching every part of the world. There is still a big need for training in their use and application to solve problems. Sanitary engineers and engineering associations could play an important role in this training process

Print information will continue to go hand-in-hand with electronic publishing.

Pricing for sanitary engineering information is reasonable and moderate compared to other subject fields.

References:
Naisbitt, John (1982). Megatrends. Wartner Books, New York
Toffler, Alvin (1976). Future Shock. Random Books, New York

COMPUTING - NOT YET HALF WAY THERE

N Cullen

VRc Engineering, PO Box 85, Frankland Road, Blagrove, Swindon, SN5 8YR, England

ABSTRACT

Past trends, progress to date and current developments in UK Water Industry computing and operational practice are used to speculate upon the speed and direction of changes in computing. Results/effort analysis is suggested as a means of identifying activities where innovation is required and relevant current research requirements are outlined. Current training aids for building multi-discipline teams are set alongside the requirements of systems engineering. The paper expects a fifty-fold increase in computing capacity by the year 2000, the earliest developments being in Instrumentation, Control and Automation, and Management Information. The growth of integrated corporate computing will depend on cultivation of greater unity within organisations and the early agreement of standards for data, software and communications.

EXTRAIT

Les modes passées, le progrès actuel et les développements courants dans l'informatique et la pratique opérationnelle de l'Industrie des Eaux du R.U. sont utilisés pour spéculer sur la rapidité et la direction des changements de l'informatique. Une analyse des résultats/efforts est suggérée comme un moyen d'identifier les activités où l'innovation est nécessaire et où les besoins de recherche courante correspondante sont soulignés. Les facilités de formation actuelle créant des équipes multi-disciplinaires sont établies selon les besoins de fabrication de systèmes. Cet exposé espère une augmentation de la capacité informatique cinquante fois plus importante en l'an 2000, les développements les plus récents étant l'Instrumentation, le Contrôle et l'Automatisation ainsi que l'Information de Gestion. La croissance de l'informatisation intégrée de l'entreprise dépendra de la continuation d'une plus grande unité dans les organisations et de l'accord prochain des standards de données, de logiciels et de communications.

KEYWORDS

Computing, Integration, ICA, Automation, Digital Mapping, Team Building, Innovation, Water Distribution, Information Systems, Telemetry, Biosensors, Hazard Assessment, Manager Development, Systems Engineering.

INTRODUCTION

The theme of this paper is change: continuous rapid rise in computing power, fall in computing cost, and wide-ranging increase in feasible applications; lack of change in the objectives of a water undertaking, but a growing burden of responsibility, particularly for the environment. There will be an accompanying change in the nature and volume of information which computers could handle effectively.

People's basic needs, fears, aspirations and personalities change little, although their skills and attitudes can. If the new technology is going to serve us, it is the people in organisations who will turn it from 'toys' into tools. People need the right atmosphere in order to work together. This is a personal challenge for those who lead our organisations.

The purpose of this paper is to asist people to accept and adapt to inevitable change, and to discern necessary or desirable change. Trying to predict the future creates a vision which will encourage action; looking backwards moderates our expectations and reminds us of the unsolved problems.

Long-term predictions are difficult to make, and usually wrong. The reader is encouraged to make his own predictions. The paper is built around a framework of the S-curve or 'Law of Diminishing Returns'. The S-curve identifies three stages for any technology: Innovation, Production and Limitation. The ends of the curve are the interesting parts. At the innovation end, the seeds of the future are being planted and one can guess the future from the shape of the embryo. At the limitation end, technology has reached a limit; the need for change is widely felt but one is not clear, without further investigation, what changes to make.

Some change is the natural response to external pressures or internal interests; these are listed with a few facts, comments on experience in this and other industries, and selected references. The detail of how particular types of computing technology can be used is well expounded in numerous conference proceedings, journals and periodicals, and a limited number of books. It will not be elaborated here.

The structure of the paper is as follows:

Water and Computing:	A short overview.
S-curves:	Some instances of their relevance.
Pace of Development:	Landmark reports in UK Water Industry computing, with indications for future growth.
Areas of Change:	Current areas of concern which the Industry is tackling.
	Current interests in information technology with comment on relevant issues.
	Limits and innovation - five areas where limitation is leading to innovation.
Scenario 2000:	A speculative but plausible view of a works manager's day in the year 2000.
Discussion and Conclusions.	

WATER AND COMPUTING

In 1974, the UK Water Industry was reorganised, giving each regional authority responsibility for all aspects of the water cycle - securing and augmenting sources of supply, distributing water to consumers, collecting waste water, treating it, cleaning up rivers, collecting money and managing the workforce.

In addition to the expected problems of reorganisation, there were unpleasant surprises - treatment works neglect, then underground dereliction. Adding to the resultant pressure, Government and public made the not unreasonable demand that the Industry produce facts and figures to prove firstly, that it was doing its job, and then that it was doing it well. Government constraints and rising wages made it necessary to consider cuts in operation staff. Many respected senior staff have departed the Industry over the past few years. Reorganisation has made it more possible to recognise and deal with problems which are common to all of the authorities. Research and Development has been retargeted on strategic issues. International legislation and concern about the environment is increasing, and leading to requirements for standardised data storage, and handling (Otter, 1985).

Computing, born 40 years ago, is bringing a new Industrial Revolution. Today's young managers are children of the computer age, the first to use computers in their higher education. Finniston (1982) charts periods of intense innovative activity - innovation being defined as a successful invention. The last cycle of innovation peaked in 1937 and the next is predicted for 1992, based on inventions of the 1960's and 70's. The European Strategic Programme for Research and Development in Information Technology, ESPRIT 1, has a budget of about £1,000 million and ESPRIT 2 is now being planned involving 30,000 man years of effort (Alvey, 1987). We all sense the acceleration of change in computing, and therefore Finniston's prediction rings true. Change is inevitable and international.

'Water and Computing' was the theme of a 1986 conference in Paris. The introductory papers give a comprehensive summary of current issues (Bediot, 1986). Figure 1 illustrates some of these; few are unique to the Water Industry. Two convergent technologies - computing and telecommunications - open wide possibilities for operational monitoring and control. New sensors and data capture methods are needed, but must be integrated with existing ones. New display methods and database enquiry languages make information more accessible and useful. Quality control of data is important now that it has multiple uses and users. Business objectives must regulate the systems development cycle. We now have to manage not just the water cycle but flows of computerised information.

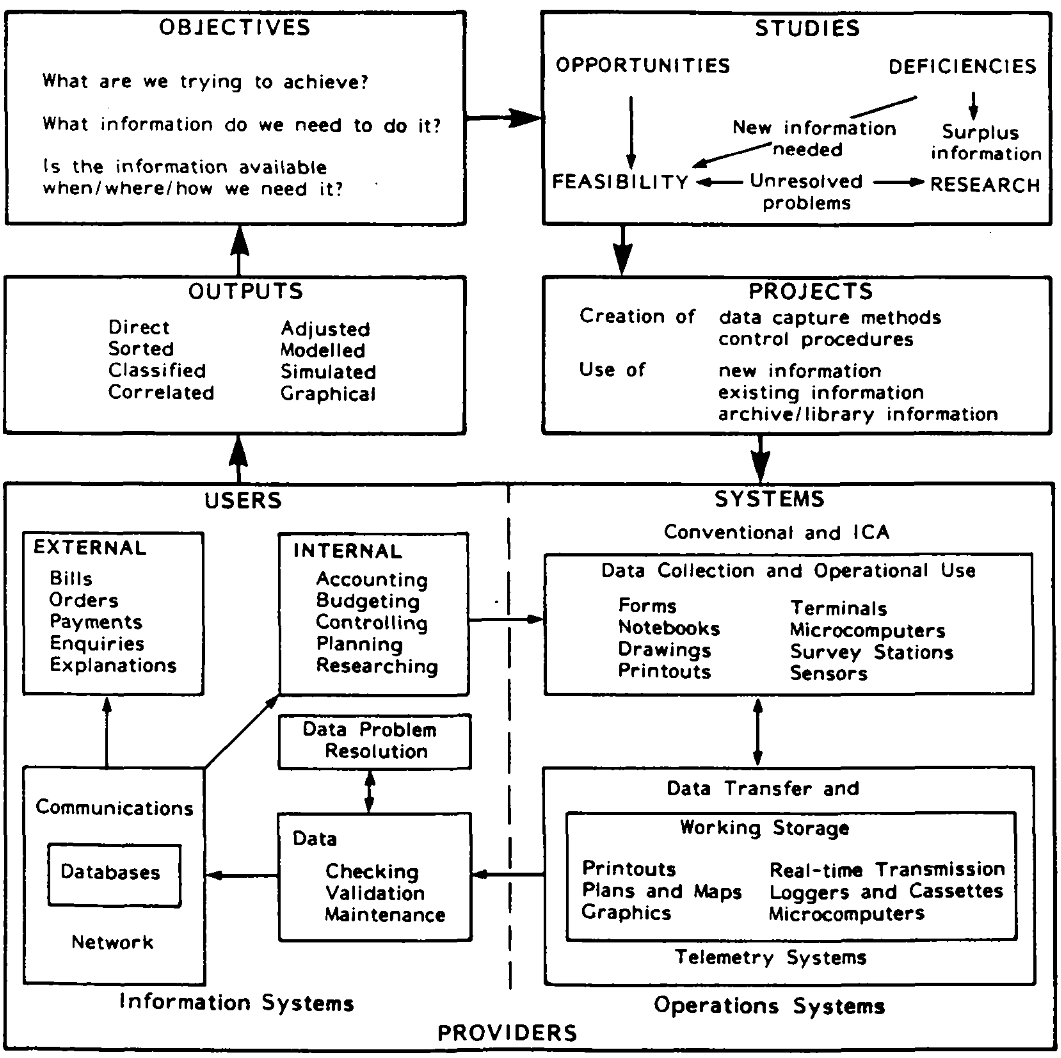


Fig 1 Systems Design and Implementation Cycle - Key Words and Ideas

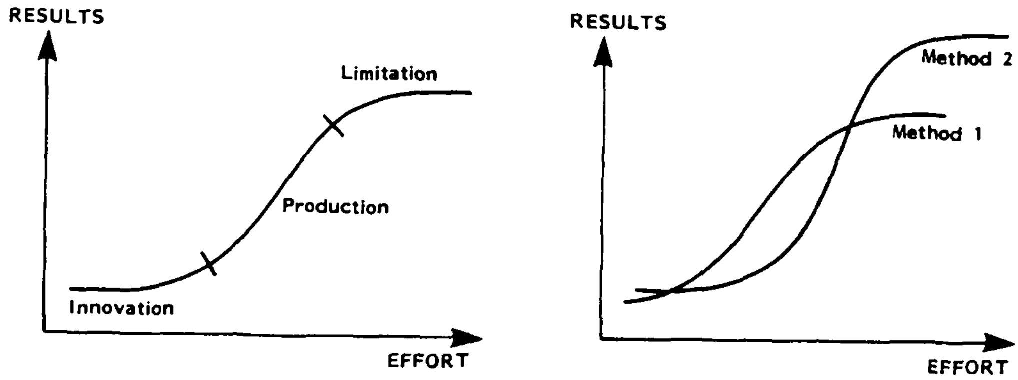
In 1987, UK Regional Water Authorities are half-way to the end of the century, but much less than half the available computing potential has been realised. Hence the title of the paper.

S-CURVES

Foster (1986) has suggested S-curve analysis as a route to competitive advantage, particularly in volatile high-profit 'leading edge' industries. It also provides a way of looking at research and innovation needs in our own stable, conservative and low-cost one.

A recent instance of the S-curve in the UK Water Industry is the work on sewerage. In the late 1970's, predictions of the "end of the world" were commonplace. Vast networks of Victorian sewers seemed to be reaching the limit of their useful life both structurally and hydraulically. This awareness that a limit was being approached led to a search for a new solution. A better understanding of the physical problems linked to cheaper and easily available computing, and innovative technical solutions, has enabled the Industry to provide better service using existing assets and within existing budgets. (MacPhee and Knott, 1986).

Sometimes there is an irresistible "snap" to a new way of doing things. Foster shows this as a discontinuity in S-curves (Figure 3). Once a certain point has been reached in a relative viability of two differing methods, the changeover can be rapid and alarming. In the USA, bias-ply tyre manufacturers lost 50% of the market to radials over an 18 month period in 1977-79.



S-CURVE EXAMPLES

Fig 2 Technology Stages

Fig 3 Competing Technologies

We have seen a similar phenomenon in the growth of personal computing. The "snap" was caused not just by the availability of hardware. It was a combination of users, user need and awareness, plus software which met an appropriate level of user skill at a price and volume which made it worth developing. People are a vital part of the equation.

Foster states that in 1907 a seven-masted cargo ship, in which manoeuvrability had been sacrificed for speed, capsized while at anchor. The limit of wind driven cargo vessels had been reached and steam progressively took over. Subsequent history illustrates many of the features of change: Hybrid solutions, fierce but unavailing resistance from the established methodology, and subsequent attacks by successive developments - turbines, diesel engines, hovercraft and, topically, bridges and tunnels for channel crossings. Today there is much diversification in sea transport, each type of vessel occupying a particular niche. The course of computer deployment is likely to be similar.

In the "Production" stage of an S-curve, efficiency is all-important: are we doing things right? However, at each end, effectiveness is the key: are we doing the right things? Worthwhile change can start with an examination of limits - what factors are preventing productivity improvements? Such studies require some imagination and understanding of the components of the problem, and research organisations have a role to play. Once a limit is discovered, the required research and development can be specified and undertaken. A later section focusses on some current limiting problems.

PACE OF DEVELOPMENT

How far have initial expectations of computing in the UK Water Industry been met? In 1973, with Water Industry reorganisation looming, the Department of Trade and Industry commissioned a report from International Computers Ltd, then the leading computer supplier to the Water Industry, entitled "Data Processing in the Water Industry - The next 10 years" (ICL, 1974).

At that stage there were 67 ICL 1900 series computers, 7 other ICL machines and 30 machines from other suppliers. The total memory capacity would be of the order of 20 megabytes, about one tenth of today's figure. The computer system application areas identified by the report are still current and are listed in Table 1. Notable additions since are operational computing, telecommunications and ICA, personal computing, customer complaints, works order generation and digital mapping.

In 1984 a Water Authorities Association working group reviewed the level and distribution of expenditure on computing. The following emerged as the major production systems, in decreasing order of expenditure: Billing (44%), General Ledger (16%), Scientific and Technical - mainly Water Quality Archive (12%), Payroll (7%), Creditors (2%), Stores (2%), Transport (2%), with various other applications (15%). Growth from 1980-84 was estimated (Figs 4-7).

It is clear from the available evidence that financial applications have dominated the scene to date. Only recently has control of data processing begun to move from finance departments to information services managers. Most of the tangible benefits of automating financial and administration systems have now been attained. Data processing managers are striving for greater efficiency in maintaining these systems. As the cost of hardware falls and the power of minis and micros increases, more and more applications will become viable. Operational applications have to date been the poor relation, because of the problems of geographic dispersion, lack of standard procedures, difficulty in cost justifying, and lack of user awareness of the possibilities. Some of these factors are now changing.

Table 1 Water Authority Computer Application Topics - 1974

Financial	Operational and Resource Planning	Hydrometric and Water Quality
A. DATABASE		
Consumer Records	Work Recording	Analysis - Physical
Billing	Project Recording	- Biochemical
Debt Holder Records	Stock Recording	- Biological
Interest Payments	Maintenance Recording	Licensing - Abstraction
Supplier Records	Throughput Monitoring	- Discharge
Creditor Payment		Climatic
Purchasing		Well and Borehole Levels
Payroll		Soil Moisture
		Rainfall
B. CONTROL		
Asset Register	Consumption Allocation	Flow Monitoring
Report vs Budget	Consumption Records	Quality Monitoring
Report vs Standard	Project Control	Abstraction Control
Cash Flow	Resource Usage Reports	Discharge Control
Programme Costing	Stock Control	
Cost Records	Conjunctive Use Model	
Accounts	Planned Maintenance	
Unit Costing	Flood Warning	
Internal Charging	Waste Detection	
C. BUDGETING		
Resource Usage	Physical RWA Model	Quality Targets
Cash Flow Model	Physical Resource Usage	Water Balance
RWA Financial Model	Manpower Planning	
	Resource Optimisation	
	Computer Aided Design	
D. PLANNING		
Demand Elasticity	Project Planning	Resource Modelling
Financial Modelling		Quality Modelling
Economic Modelling		
Source: adapted from illustration 3.1 in ICL (1974)		

Figures 4-7 show UK Water Industry computing power to be growing rapidly with no levelling-off in sight. We are now beginning to see the integrated use of mainframes, mini- and micro-computers each in a range of applications to which it is best suited. However, the situation will remain fluid because yesterday's mainframe is today's microcomputer. Similarly, it is predicted that today's mainframe capacity will be available on microcomputers within a few years.

COMPUTING CAPACITY IN REGIONAL WATER AUTHORITIES

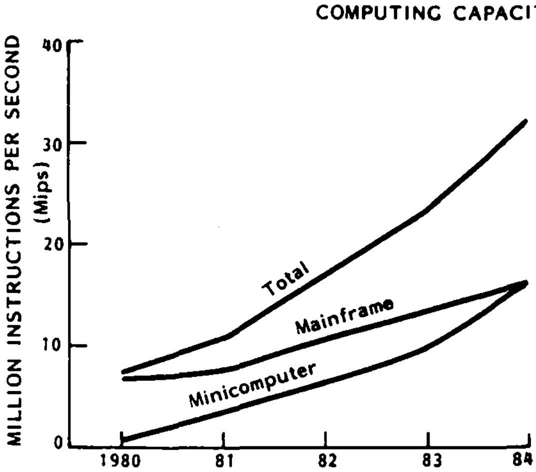


Fig 4 Processing Power

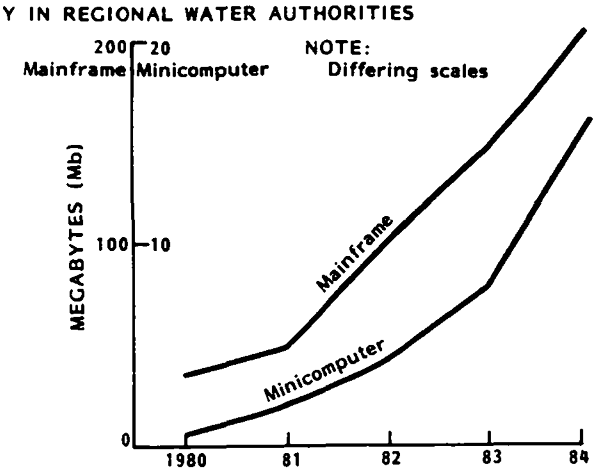


Fig 5 Main Memory

Source: derived from internal WAA study

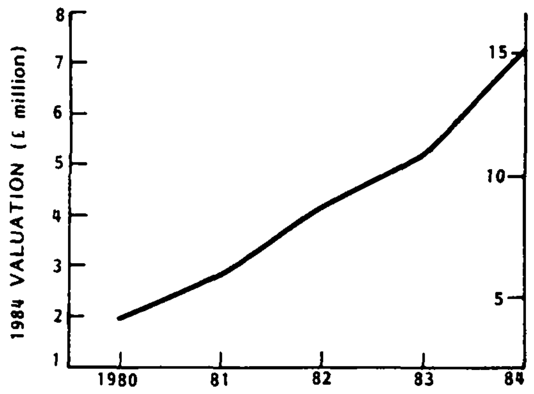


Fig 6 Terminals and Microcomputers

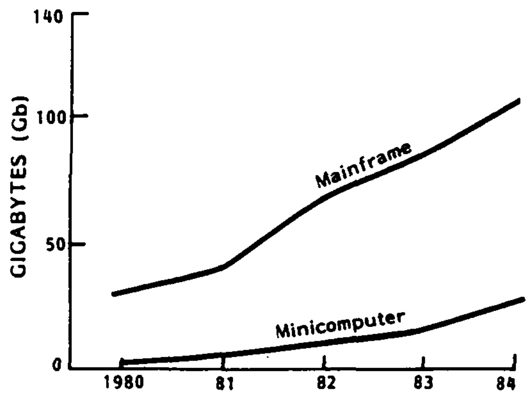


Fig 7 On-line Storage

The graphs exhibit a growth in the range 25%-45% per annum. This is in line with international growth in the power and storage capacity of computers over a 26 year period (Churchouse, 1982). Planning assumptions in other industries range from 30% to 60%. Compound growth of 30% to the end of the century gives a 30-fold increase, and 40% growth gives nearly 80-fold. *Therefore a conservative estimate is that in the year 2000,* computing capacity in Water Authorities will be fifty times greater than now. Because the cost of computers will continue to fall, this does not imply a corresponding increase in real expenditure.

The ICL report identified a stock of inherited software worth at least 400 man years. It estimated the development effort for required software as 560 man-years average per annum over the industry as a whole, and stated that up to 48% of this could be saved if the authorities cooperated in development of modular systems. A recent estimate gives 1984 development at about 490 man-years per year. The collaborative ventures recommended in 1974 have not occurred. Can water authorities circumvent the present shortage of Information Technology skills by co-operation in software design, specification and development?

AREAS OF CHANGE

Current Concerns

Current concerns stem from external pressures, disasters or warning mishaps, and new possibilities generated by changes in culture, politics and technology. Several of our current concerns will require innovative solutions. Some will involve computers; all will involve people. Table 2 lists some current concerns, together with other factors which need to be considered in planning.

Table 2 Factors Influencing Change in the UK Water Industry

What Will Change Little	What May Change	Current Concerns
Need for Water	Pollution and Environmental Pressures	Disaster Planning
Topography and Rainfall Patterns		
Buried Assets (Pipes)	Plant, Equipment and Above-ground Assets	Asset Management
	Cost of Power and Fuel	Energy Savings
Basic Nature of People - Employees	Employees	People Management
	Employee Attitude and Skills	
Basic Nature of People - Customers	Social Attitudes	Customer Services
	Economic Circumstances	Performance Measures
Population Distribution	Industrial Development Patterns	Charging and Metering
	Governments	Privatisation
	Legislation	Regulation and Standards
	Available Technology	Corporate Computing
Information Needs	Information Needs	
- Regular/Routine	- Planning and Reaction	EEC Legislation
- Periodic	- Consultation and Explanation	
	- Emergencies and Defence	Incident Response

Current Interests

Current interests - those applications being actively pursued because they are perceived to be of benefit to an organisation - give strong clues about development over the next 5-10 years. In 1974, the talk was of individual applications. Those bringing immediate benefit in terms of cash flow, control and manpower savings were implemented first. Today, the interest is in "enabling systems": management information, office automation, integration, data bases, ICA (Instrumentation, Control and Automation) asset management, decision support and digital mapping. These are topics at the innovative end of the S-curve and a few comments on each will clarify the likely developments. Telecommunications is a less visible but vitally important topic to be addressed now (Barron and Curnow, 1979).

Management Information. One Water Authority has stated that its existing information systems are inadequate for future and current needs, and has allocated 5% of capital expenditure over the next 5 years to an integrated data management system (TWA, 1986). Other authorities have similar plans. This is undoubtedly the right direction to move, but we can learn from past projects.

For instance, during 1970-77, $26 M were spent on a project to develop an integrated municipal information system in the USA. Like the seven-masted cargo ship, it failed to accomplish its stated objectives, but as an experiment "it provided valuable insight into the difficulties of organising and implementing major technological development and diffusion efforts in the public sector". The circumstances surrounding that project parallel features of our own industry today, and the post mortem report (Kraemer and King, 1979) should chasten our enthusiasm, approach and expectations regarding large, integrated systems.

Integration. Integration can be defined as the process of making data, information and the data handling services available to everyone in the organisation who needs them, regardless of the original purpose for which the data were collected or the service developed.

The fundamental problem is that when we try to fit systems together, complexity grows rapidly (Table 3). Each new version of software, each set of hardware, each department, each databank etc. potentially constitutes a system. Every interface between systems must be planned, designed, implemented and maintained by computing staff and this requires effort. Without a carefully thought out and consistent set of standards, the dream of integration turns into a nightmare of incompatibility.

Table 3 Growth of Complexity

Number of Systems (S)	Number of n-way Interfaces Possible (I)								
	n= 2	3	4	5	6	7	8	9	10
1	0								
3	3	1							
5	10	10	5	1					
10	45	120	210	252	210	120	45	10	1
					$I = S!/[n!(S-n)!]$				

It is widely believed that integrated corporate computing will have a higher benefit/effort ratio than the current situation of "personal" and "departmental" computing - i.e, the limiting value of performance is higher. However, the number and scale of organisational and technical steps required to set this innovation in train is probably seriously underestimated. Integration is more an organisational problem than a technical one - standards can be policed only by consent, and a technically poor system with a spirit of cooperation may be more effective than a technically sound system with an atmosphere of departmental conflict. (De Carmoy, 1986).

Databases. Relational databases - where data are stored in a large number of tables which can be linked together easily by user enquiries - have a powerful contribution to make in providing management information. The required techniques of data analysis - grouping the data to provide flexibility in meeting user needs - were invented in the 1970s. The software to turn dream into reality is available but still developing. Database management software enables users and programmers to build in a few hours or days systems which used to take months or years. However, relational database systems use a lot of computing power and generate a large load because of their popularity with users.

The cost of implementing a database project is typically split equally between hardware, software and data conversion. If new data are required from operational departments, the data costs may assume a much larger proportion of the total.

Outline data analysis is the right place to start in defining user information requirements, and standards for data interchange between users and systems. The effort will not be wasted if it is well done now.

Digital Mapping. Digital Mapping technology offers the exciting possibility of linking large scale urban maps to an asset database with very powerful enquiry and display facilities. It is often linked in people's minds with computer aided design and with the background display facilities required by some ICA systems. Digital Mapping is, however, significantly different from CAD and ICA, and unlike these it cannot be convincingly cost-justified, mainly because of high data collection and conversion costs. (WRc, 1987).

WRc led a collaborative 15 month Digital Mapping project which ended in September 1986, to assist the UK Water Industry in setting directions for this technology. The data problem is particularly severe, as many of the assets require resurvey prior to entry on any system, and only 10% of the required background maps are currently available for the UK. The organisational problems of handling the data capture, validation and input outweigh the technical computing ones. (Hooper and Sinclair, 1987). Full scale operational trials in the Severn Trent Water Authority have shown that allowing for working storage and system software, the national data storage requirement for mapping is probably about the same size as the total UK Water Authority on-line storage capacity in 1984.

This, and the complexity of the multi-site, multi-user map management and update software required will ensure that many years elapse before the full potential of Digital Mapping becomes reality. There is much international activity (Blakemore, 1986). What happens will be significantly affected by the extent to which the UK Ordnance Survey and the various major utilities collaborate on both map production and map storage. Each authority should integrate Digital Mapping into its overall information strategy.

Office Automation. In 1981-85, £7 M was spent on 20 office automation pilot studies sponsored by the Department of Trade and Industry. Three aspects were addressed: Text production, case handling and management support. Case handling is the idea that all aspects of a "case" can be brought together by the system - in the Water Industry a case might be a customer, a project, an incident, or a planning proposal.

The final report (DTI, 1986) provides warnings and guidelines for management, but does not advocate blanket introduction of office automation. It states that "given better technology, case handling applications offer great potential but little was realised in the pilot trials" and "the installation of text production systems is likely to remain partial and geared to specific applications until the cost of the technology falls"; "organisations should focus on high value databases, business planning and other applications with specific benefits to managers". Asset management is a topical area for Decision Support in the Water Industry. The DTI Report recognises that many organisations have some "irresistible applications" and suggests criteria for identifying these. "Standards" and "People" issues are covered also.

ICA. Instrumentation, Control and Automation is the area in which the greatest development is likely over the next few years. This is because of the expected benefits, which are exemplified below for the collaborative AWA/WRc project in the Colchester Division of Anglian Water Authority. The project involves a large number of dispersed sewage pumping stations and treatment works which have a high manpower cost for travelling, inspection and maintenance. (Berry, Biss and Eastman, 1985). Contracts let to date cover 45 sewage treatment works and 160 sewage pumping stations but there is potential for substantial further work.

Table 4 shows, in round numbers, typical arithmetic for the project at 1983 prices. Additional uncosted benefits include reduction in vulnerability to industrial action, the number of dirty or dangerous jobs, requirements for sampling or analysis and of environmental damage caused by plant malfunction. More effective use of management effort and maintenance staff is expected, and better plant performance may delay the need for extensions.

Table 4 Cost Estimates for Colchester ICA Telemetry Scheme

Capital			Revenue	
Item	Life (Yrs)	Cost (£000)	Savings	£000 p.a.
Central Computer	10	100	Labour (60% saving)	190
Telemetry Equipment	10	240	Supervision & Management	50
Outstations	10	330	Transport	10
Modifications: Instrumentation & Electrical	20	880	Power (15% saving)	20
Modifications: Process	20	400	Sludge Disposal (17% saving)	30
Subtotal 1		1950	Total Savings	300
Software		100	Additions	
Specification, field study, design and Commissioning		300	ICA Engineer/Technicians Instrument Spares etc	60 20
Subtotal 2		400	Total Additions	80
Capital Cost =		2350	Net Saving =	220 p.a

(1983 Prices)

The large number of sites with similar problems gave the project some "mass-production" aspects. The design uses a "software solution" for local control; site hardware can accommodate a combination of different pieces of configurable software. Twenty seven different software modules will be provided, each based on a good understanding of a particular process and associated operational practice. There is little standardisation of outstation design and communications protocols between suppliers, and hence the software can only be standardised at specification level; the actual programming is hardware-dependent and thus part of the supply contract. Design and software cost as much as the hardware, and therefore software standardisation provided substantial cost savings.

The software solution also offers scope to enhance the benefits, e.g, optimisation features to improve works performance, monitoring features to alert management early regarding incipient plant failure or process problems, fault tolerant control with automatic testing of instruments and infrequently used plant, manual intervention, provision of management information and reduced need for local control panels. The system manager is considered part of the control loop. His role has to be clearly identified so that he is presented on a computer terminal with the information he needs in the right format for him to do his job effectively.

Against these benefits stand the need for new types of specialist to install and maintain the systems, and for operator/manager retraining. A thorough and comprehensive analysis of the initial requirements was undertaken; the project team comprised research, operations, civil engineering, ICA systems, systems supplier and finance personnel.

Limits and Innovation

The Limitation and Innovation stages often co-exist, because today's problems provide the stimulus to find tomorrow's solutions - 'necessity is the mother of invention'. Four problem areas of the water business will be considered: Water Supply and Distribution, Information Systems, Sensors, and Disaster Response. A fifth, Teamwork and Systems Engineering, recognises the work being done to help train water industry managers to handle change, and manage multi-discipline projects.

Water Supply and Distribution. If we consider the S-curve concept in the field of water distribution, the symptoms of limits having been reached are apparent, but are masked by the reduced growth in water demand during the industrial recession. Increasing amounts of effort are having to be applied to obtain ever smaller improvements in performance using existing technologies. Continued innovation is required to open up new opportunities.

Leakage control programmes (Goodwin, 1985) are a recognition that it is pointless to put large resources into treatment and pumping, or building new sources of supply, if large amounts of water are lost on the way to the consumer and can be retained relatively cheaply.

The question now being addressed is, 'how much could we improve performance of our supply and distribution networks if we knew more about what was actually happening hydraulically and if we knew and could improve the internal condition of the asset?' The problem is two-fold - currently a lack of knowledge because it is difficult to "see" inside a pipe - but subsequently there could be an overwhelming deluge of data which will not improve our knowledge unless properly handled. There might subsequently be an improvement in performance of our networks if there proves to be scope for controlling them.

WRc has recently specified software for a decision support system to help use telemetry and control to best effect in water supply. The aim is to assist the manager to analyse telemetered data for monitoring and control, using the techniques of short-term demand prediction, pump scheduling, network simulation and analysis of leakage data. Pump scheduling can give significant savings in electricity costs and can ultimately be implemented automatically by a central controller. Leakage analysis enables investigative effort to be directed more effectively. Network simulation will calculate flows, pressures and reservoir levels throughout a simulated period e.g, 24 hours. These modelling tools can be used in 'what if' mode and are potentially valuable to help decide how to respond in an emergency. (Stimson, 1987).

For water distribution, it would be useful to be able to collate the results of pipe condition sampling, water quality sampling, customer complaints etc. in a data base and display the results on a screen backed by a digital map. We can expect to see reports of useful UK operational systems of this type around 1990. The current limiting factors include our understanding of how pipe deterioration and water quality interact, lack of data, manpower restrictions and how to handle all the information required to maintain the system.

Information Systems Requirements. Another limit being approached, which the Water Industry has in common with others, is the capacity to handle all the information being generated by it or thrust at it from outside, to discern what is important and to take the required action in the appropriate time scale. In this area, the "structured methods" being advocated by computer consultants can be a great help. However, they will make us feel uncomfortable because at all points they challenge practices and assumptions. What are you trying to achieve? Why do it this way? Have you thought about the alternatives? (Dewey, 1910).

WRc has followed leads taken by a few water authorities, to identify a generalised structure for both the data available and the activities performed at the 'grass-roots' operational level (Cullen and Murrell, 1984). These structures are an essential step in software design for information systems, and WRc is assisting various authorities to adapt the general models to specific requirements. Figure 8 shows part of a data model; Figure 9 illustrates the use of a notation for activity analysis showing the interaction with data sources.

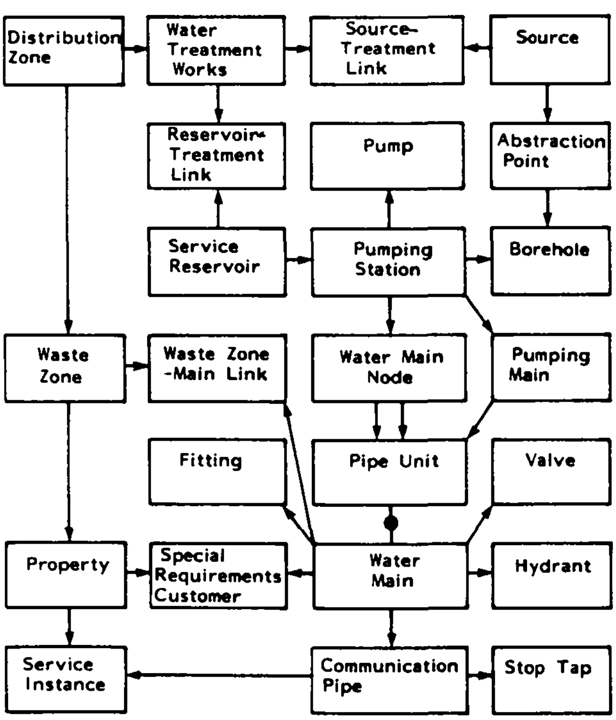


Fig 8 Part of Data Model for Water Operations

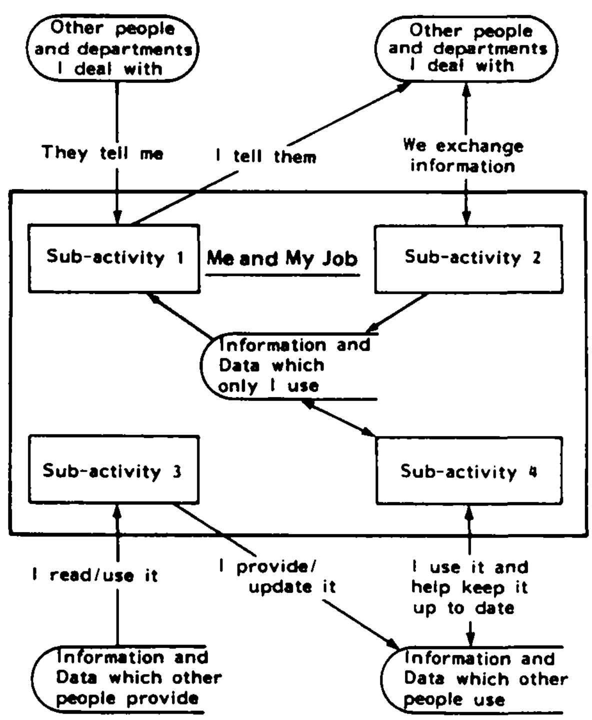


Fig 9 Activity Analysis - Notation

Sensors. Much of the vital information used operationally is biological, chemical and visual, and there is a long recognised gap in sensor technology for our industry (Cole and Evans, 1986). Where this gap is closed, there could be an explosion of applications, but until it is, many bright ideas will either remain dormant or be ineffectively applied.

Most analysis techniques search for specific substances and require laboratory facilities. What we need increasingly are devices which will say "Hey, there is something wrong here! Take a closer look and do something, quick!". Such devices are termed 'broad-band sensors'.

This is where biosensors are useful. They monitor the activity of living organisms. Fish monitors are the first example, but they are relatively bulky and expensive to maintain and do not always react sufficiently fast. The next stage is to use micro-organisms (Evans, Briers and Rawson, 1986). Here, microprocessors can help in maintaining the right environment and processing and interpreting data about the organisms.

In some situations a professional scientist is analysing and assimilating data on a range of problems of different types, and pronouncing whether the general performance of a works "looks about right" or "is a cause for concern". This is the province of Expert Systems and, if the cost and response time can be improved and each operational problem understood, could develop as one of our lines of defence against the unknown and unexpected (Burke, 1985).

Disaster Responses. Pollution in the Rhine and radioactivity from Chernobyl have made international headlines. In the UK, we have experienced serious accidental river and distribution system contamination, also flooding and loss of supply at major aqueducts in Leeds and Glasgow. Subsequent enquiries highlighted shortcomings in operational procedure and incident response (Hannah, 1986). A checklist of required actions following a river pollution incident would be complex to implement if computerised. (Owens, 1985; WAA, 1985).

New and unexpected hazards will continue to assail us. There are many unreported 'near-misses'. Some hazards will come from use of the new techniques themselves: computing, communications and automation. What are the vulnerable points of our existing systems and our new ones? What are the risks and consequences of failure? What ways are there to warn us of problems and what is it worth spending on these? Who is going to 'think the unthinkable'? Where is the forum for sharing our near-miss experiences so that countermeasures are taken before the full disaster? The newly-formed UK Institution of Water and Environmental Management is well placed to take up this role, started by its predecessor bodies (Ord, 1984). Success is glamorous, but engineers learn more from failures.

Teamwork and Systems Engineering. In order to do its job and maintain or improve performance, the industry has to address a wide range of problems and is likely to use an increasingly diverse but integrated set of solutions. The range of skills required is such that multi-discipline, multi-organisation teams will be needed to investigate the need for, design, implement and operate any new systems. There is a need and scope for innovation in helping people to work together.

Water Training, the UK Water Industry training organisation, has been working with water authorities on manager development, with tools for the analysis of personal roles and styles (Margerison and McCann, 1985), and with 'Systems Engineering' courses. Systems Engineering emphasises the need for a systematic approach to "the total problem"; Team Building aims to assemble complete and balanced teams to solve problems. There is evidence that different types of personality are better suited to different stages of the problem-innovation-production cycle and that there is a heavy bias to production-orientated personnel in water authorities (Jones, 1986; Message, 1985).

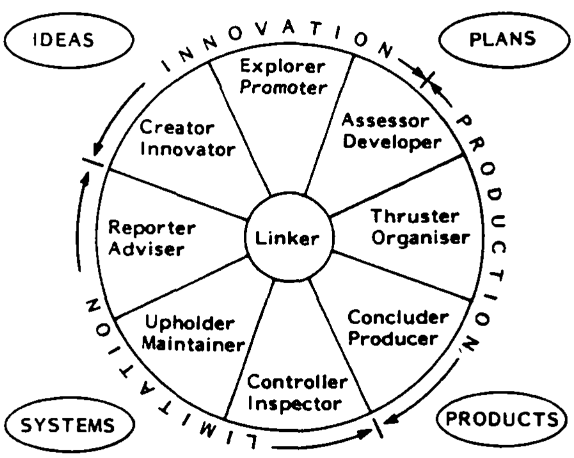


Fig 10 Personal Roles and Technology Stages

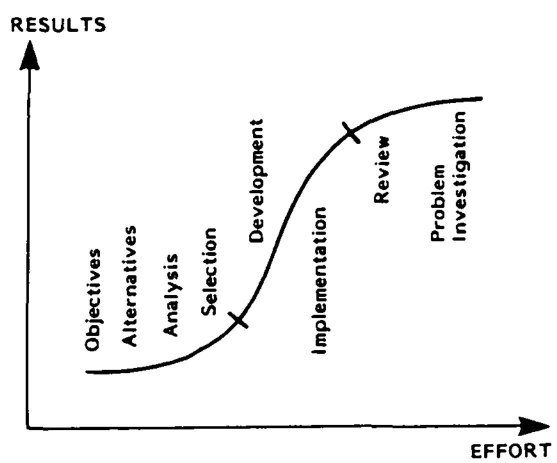


Fig 11 Systematic Problem-solving

Source: adapted from Margerison (1985) p. 16.

Many analyses are loosely based around four personality types (Jung, 1923) - the 'Sensor' who rapidly sizes up situations and people and has a zest for action, the 'Thinker' who is keen on facts, figures and verification, the 'Feeler' who is able to get closer to people and makes a good politician or salesman, and the 'Intuitor' who sees the overall pattern, and will dream and invent but is less keen on working through the detail. (Hunningher, 1986). Each individual has a different mix of these traits.

Each type of person may have difficulty understanding or communicating with the others unless the differences are recognised. Often in consequence, each type tends to congregate together and each group may take a low view of the others. Team working requires that these barriers be dissolved. (Whitehead, 1987).

Problem-solving stages can be matched to an S-curve, which in turn can be set alongside various preferred roles on a 'team management wheel' (Margerison and McCann, 1985). The leading role at each stage of problem-solving may best be assumed by a different type of person. Figures 10 and 11 illustrate a way of combining the approaches of Foster and Margerison. In order to succeed in endeavours like the Colchester ICA scheme, the Digital Mapping project, or Information Systems development mentioned above, we need to improve our understanding of how people and problems interact, and use this in project design and management.

SCENARIO 2000

The technology, problems and current developments outlined in previous sections lead one to consider one's feelings about living and working in the environment suggested by the following scenario. We should ask: Would we like it? Is it attainable? What would it cost? How could it go wrong? Would it be worth it?

"As Jim drove through the treatment plant gates, his car phone spoke a warning message, and as he stopped he could see the emergency tanks starting to fill. An automatic penstock had closed in response to adverse readings on one of the inlet biosensors. 'Another illegal industrial discharge' he thought. It was a dry day and he knew that the tank would therefore give about two hours grace to solve the problem. Forgetting home problems for the moment, he strolled into the control room.

"The Visual Display Unit told him that a warning message had already been sent to the water treatment works further down the river, but that within his own plant there were no unusual readings on intermediate sensors, suggesting that the intake protection had diverted most of the discharge. Substance-specific sensors at the major industrial installations in the catchment were being polled by telemetry to pick up abnormalities.

"So far so good. The chances were that somewhere, an alarm was ringing and a manufacturer taking steps to control the deviant discharge. The worst previous case had taken only 30 minutes to identify and isolate the source.

"He turned his attention to the day's routine.

"The screen told him that he was requested to work at a plant 30 miles away next week. 'Personal diary' he requested, and the machine, recognising his voice print, brought up the details from his home computer over the telephone link. Several evening engagements would clash with the travelling, so he declined the request, although he rather liked to have the change of surroundings. It gave a chance to meet colleagues and chat over recent events, technical and social, in the organisation.

"Standardisation of control procedures and data presentation had made specialist staff more interchangeable. Those stormy years he had spent on an authority working group were paying dividends now. Key principles of standardisation had been published nationally, so although each Authority had implemented in different ways, only a few day's training would be needed if he ever wished to use the information and control systems in a neighbouring organisation.

"He was a bit annoyed about the discovery from his home terminal that his water rates had been paid a day early but his salary was a day late. 'In the days of paper I could control my outpayments', he thought, forgetting the time saved by being able to do most transactions from home. He contemplated sending a good humoured complaint to his friend in Headquarters, via the electronic mail system.

"Back to business. He gave the 'Incident' command to the terminal, which started to generate a pre-determined series of coloured plots giving situation reports from the central and local databases: Weather radar, river level and water quality information. Specialist advice would be available on the videophone from an HQ team, where an expert system held details of previous incidents at his own site as well as the rest of the Authority. The national incident database at Stevenage was also available on-line if required via a microwave link.

"An hour later, the chemical characteristics of the discharge had been determined in the laboratory, but the factory discharge monitoring system had not identified the source. He therefore notified the regional incident room with details of the discharge and plant situation report. Coordination was now their responsibility.

"He knew the next steps from last year's major incident exercise but he called up a list on the printer as a check. The substance would be compared with a list of relevant chemicals generated or stored by factories in the town. The sewerage agents would be notified and crews instructed using digital maps generated on vehicle terminals, to take samples from manholes near each plant. Downstream water treatment plants would be warned to make short-term demand estimates and step up feed to service reservoirs now so that they could shut down in rotation if a slug of polluted material had to pass down the river. A number of farmers with livestock adjoining the river would be notified by telephone. At his own plant, details of the discharge were fed to an expert system so that the technical processes could be reconfigured to handle the contaminant. When he was satisfied with the answers the machine proposed, he would give an instruction to start treating the emergency tank contents. The computer's database was built on past experience of plant operation.

"During the afternoon, the source of the pollutant had been identified at a registered factory. The discharge sensors had failed to alarm because of inadequate maintenance. The additional authority process costs had been calculated and the discharger given a preliminary estimate of the bill he would have to pay. Perhaps it would have been cheaper to have self-checking instrumentation? This treatment plant was able to handle the discharge and it was not necessary to alter the operation of clean water intakes downstream.

"At 5 pm, Jim paused to fill in his electronic timesheet. A colleague would be on call that evening, with ability to call up key plant information on a home terminal. Jim typed the codes for 'normal duties - 7 hours' and picked up his jacket to go home."

DISCUSSION

An important feature of Scenario 2000 is that the manager is still in control, and he still has an intuitive 'feel' for how his plant works and interacts with its environment. Face to face human contact and social life are maintained as a feature of the organisation. The information and control system 'belonged' to Jim - he had helped to specify it through the working groups. Some features of the technology might not progress much: full voice recognition is reputed to be difficult; outside bodies, e.g, the farmers, were still contacted by telephone. Life is a mixture of old and new methods and technologies.

The computing tools - most of which exist in isolation now - would require to be linked together as a robust system if managers and operators are going to trust and rely on them. Progress is likely to be limited by the availability and cost of skilled manpower to collect and check data, and to design and write software, rather than by shortcomings of hardware and communications. Communications and control links are vulnerable to interception and interference; could breaking into computer systems become a widespread hobby?

The governing factor in the pace of change seems not to be the availability of ideas, or inventions, or even availability of technology off the shelf; it is the rate of transmission of ideas, changes of attitude and development of skills in an organisation. Talking and working together on real live problems is often the most effective and rapid way of achieving necessary change. Perhaps the level of inter-organisation co-operation and personnel secondment should be increased? A rule of thumb in some industries is "what you see on the lab bench now will be fully operational in the field in ten years time". This is certainly true of recent WRc experience in water and sewerage. Foster identifies the perpetual research funding dilemma - how much money should we throw at the old increasingly ineffective method and how much should we divert into finding a new one? UK Water Industry research into IT applications is under-funded.

Four principles govern most computing applications today: Business objectives must govern development; good requirements analysis is the key to effective data management; hardware is not a serious problem; standards are essential. Four more have specific relevence to the Water Industry for some years to come.

Firstly, software is a bottleneck (Barron and Curnow, 1979). To get full benefit from available technology, we must be efficient in software design and production. The techniques of software engineering must be deployed: Structured analysis, modular design, quality control and "fourth generation" languages. Secondly, operational problems and understanding often limit us more than computing ones: Sensors, data capture, data validation, distribution system maintenance, manpower deployment come into this category. Thirdly, innovation is the key to further progress. Innovation by the managers and operational staff of each organisation, changed working practices, new management styles and new uses of the technology and techniques introduced by research and development teams. Fourthly, innovation requires an atmosphere of trust and cooperation, and healthy competition rather than conflict.

Can organisations staffed by Engineers, Scientists and Accountants make the change to widespread use of computers without large scale staff turnover? Some Civil Engineers are already enjoying a change. The information, computing and communications projects of the next few decades may well be as large and expensive as, and possibly more complex than civil engineering projects. Engineers and accountants in the Water Industry at present need not fear that they will be displaced by hordes of computer specialists, so long as they will recognise that their underlying aptitude is not in their original discipline but in project management and systems.

Will a traditional conservative industry accept the risks of change? It is pertinent to ask whether we have any choice, and whether the risks of resisting change are greater. With manpower steadily declining, we are increasingly locked into using new technologies in any case. Unless we use them it will be difficult to recruit engineering, clerical and operational staff. What image do we wish to project to employees and customers: robust, dependable and ponderous, or exciting, futuristic and volatile? Are the two sets of characteristics incompatible within a single organisation? An intelligent appraisal is needed of the risks introduced by the technology and manpower reduction, particularly of our ability to respond to crises and emergencies. All staff have a role to play in this although specialist investigations are also necessary.

A major factor influencing the pace of development will be whether we take stock and chart a realistic way forward. The Water Industry has taken a battering from economic and political pressures. It has perhaps been naive in assuming that its efforts to provide a vital public service at the lowest possible cost would automatically be recognised. Public image and employee morale have, until recently at least, been declining. Contributory factors listed by one Chief Executive are reduced capital expenditure, haphazard manpower reductions, inconsistent decisions, inflexible systems, and not having employees involved in the thinking.

Change in any industry - and water is no exception - is stimulated primarily by external pressures, most of which are foreseeable, he said. Hence, it is reasonable and possible to plan, setting out clear priorities, defining investment strategies and business plans but making provision for frequent updating in line with long-term aims. He identified the need to develop flexible systems and cultivate flexible attitudes. A major challenge for senior management is to re-create and sustain the atmosphere of trust and cooperation which is essential for innovation to flourish (Peters and Waterman, 1982).

CONCLUSIONS

- Present trends suggest that the available computing capacity in the Water Industry in the year 2000 will be about 50 times greater than in the early 1980s.
- The dominant growth area during the early years will be in ICA which can frequently be cost justified now, although the full potential can only be realised with better sensors.
- Shortcomings in management information systems are being tackled.
- Growing dependence on automation does, however, require an imaginative appraisal of the induced hazards.

- o Consolidation of departmental computing and user awareness will lead to a natural growth of applications, and a progression into corporate computing. This progression will, however, be dependent on the early establishment of a corporate unity of purpose, and development of standards for data, software and telecommunications.
- o Automatic control of water distribution networks must await further development of our understanding of the physical operation.
- o Many applications, but notably digital mapping, are dependent on organisations' ability and willingness to collect and handle the data as well as improvements in database technology and performance.
- o The feasibility of increased co-operation between authorities on software specification and design should be considered.
- o Computing technology is unlikely to reduce the cost of water services in real terms, but it can enable the industry to be more effective in its present tasks and to be more responsive to external change and pressure.

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SESSION 4

SEANCE 4

Chairman
Président R. URBISTONDO

- Recent Progress in Civil Engineering applied to Constructions for Water Supply Companies

  Progrès récents de génie civil appliqués aux constructions pour les entreprises de distribution d'eau

  H. Crommelinck

- Countermeasures for the Earthquake-proof Improvement of Water Supply Pipelines

  Contre-mesures en vue de l'amélioration de canalisations d'eau à l'abri des tremblements de terre

  T. Iwamoto, H. Miyamoto, S. Hojo

Discussion

RECENT PROGRESS IN CIVIL ENGINEERING, APPLIED TO CONSTRUCTIONS FOR WATER SUPPLY COMPANIES

ir. H. Crommelinck*
Engineering Department of Antwerp Water Works, Antwerp-Belgium

ABSTRACT

In this contribution to the technical and scientific programme of the Symposium "Water 2000", some aspects of the recent evolution in civil constructional engineering, as applied on constructions for water treatment purposes, are discussed.
As a guide-line through this paper, the chronological building up of a construction, from the first draft to the final realization, including exploitation and later renovation or the complete renewal, will be followed. Building up a synopsis of the new techniques and applied materials is thereto the main aim. Like a red wire all through the text, it is continually checked to what extend these new techniques or materials offer greater possibilities to developing countries, so as to help realize the endeavour of the IWSA : "Safe drinking water for mankind."
Finally an attempt will be made to make some prognosis regarding the possible evolution of the civil engineering techniques towards the 21st century.

KEYWORDS

Constructional engineering, progress, preliminary study, in situ tests, design, construction methods, machinery, building materials, renovation, demolition.

INTRODUCTION

Professional literature as well as the media are predicting a new industrial revolution for the nineties. Its foundation was led in the early sixties, with on the one hand the conquest of space and on the other hand the awakening to the problem of food supply, of housing facilities, and of health care for an ever growing world population.

To assure the delivery of potable water in enough quantities and of good quality has always been the first aim for the water supply companies, in their contribution to overcome the existing and still growing needs.

Due to a concurrence of events and to a simultaneous development of various techniques, co-ordination and reciprocal stimulation made the possiblilities, offered by technology, evolve in an accelerated way.

The growth of the world's population and the threatening food shortages made the agricultural techniques evolve into industrial ones, based on laboratory experiments and field tests. Genetic manipulation is presently the magic word.

Mechanics and mechanical engineering are disciplines which, due to the introduction of new forms of energy, due to the evolution in electronics, and the research on new materials, have turned into automation, computerization and robotization.

The development and the growth of ever new generations of computers not only allowed to increase the possibilities of solving complicated mathematical problems but influenced profoundly almost every technological branch and administration. Personal computers can no longer be denied in our private lives.

Civil constructional engineering, a century-old practice, the skills of which were merely determined by experience and by knowledge and application of mostly empirical formulas, has participated strongly in the spectacular evolution in technology. Thanks to the knowledge of mathematical solution to the posed problems, the ability of disposing of fast and precise computers, and the urgent quest of the building trade to develop ever cheaper and quicker solutions to these problems, have been the main impulse for constructional engineers and engineering bureaus to change their working and calculating methods drastically.

The growth of both mechanics and electro-mechanics allowed to introduce new, better and safer construction machinery.
The search for new materials, the evolution in chemistry, and the acquisition of a better insight into the behaviour of these materials as a function of the imposed loads, have caused the same evolution in the same evolution in the application of new building materials.

It will be finaly tried to make some prognosis concerning a possibe evolution towards the 21st century.

As a guideline through the text and in order to better describe and arrange the new evolutions, the raising of a construction will be observed in chronological order, from the first draft till the realization, including the exploitation, its renovation and its ultimate replacement.

2. THE PRELIMINARY DESIGN. THE BIRTH OF A NEW CONSTRUCTION

2.1. The application of new techniques on the use of new materials in water treatment plants are often the result of influencing external factors, such as :

- the extension of an existing raw-water catchment might be imposed by an increasing water demand or by a regression of the water quality of the existing raw-water source;
- the adaptation of existing treatment plants as a result of the application of new treatment techniques, of changes in the composition of the raw water available, or of severer quality requirements posed by the consumers;
- the construction of a pilot plant, prelimininary to the building of a new water catchment or water treatment plant might be imposed in order to obtain realistic testing results by applicating new treatment techniques and to be able to evaluate their financial impact on future drinking water production on full size;
- the building up of water reserves, either by constructing raw water reservoirs, pe-treated water-reservoirs, or underground clear water reservoirs or water towers, might be necessary according to climatological circumstances to changes in water demand or whenever the raw water source might be threatened;
- the extention of the adduction system, coupled, if so required, to the construction of booster pumping stations or water towers, as a result of an increased drinking water demand or of a changing consumption pattern;
- the renovation of distribution systems as a result of quality or corrosion problems or by increasing piezometric headlosses;
- the development and application of new pressure-steering techniques in the distribution network or the further automation of pumping stations, in order to improve the service rendered to the consumer at the minimum cost and with a durable garantee.

2.2. The choice of the thereto needed constructions and the drawing of the preliminary sketch is no longer the work of one single person or of a few engineers which belong to one single discipline.

A constructive cooperation to realize an optimal design can nowadays only be achieved through mutual consultation between the Managment and the Engineering Department, supported by the contribution of Research and Development.

Although the knowledge of an experienced engineer proves to be an important, if not the essential contribution to the solution of the posed problems, the Engineering Department is required to dispose of a broad spectrum of possibilities and information about techniques as well as materials before drafting the definite design.

2.3. In the first place, the existence of high level professional literature and more specifically publications by colleagues in the world of water are of special help for a tentative pilot study.

The classification of the available literature in librairies, which is an appropriately chosen reference sytem, key-words, ets., although being an administrative matter in the first place, has become an undeniable help to the designers and engineers. The formation of data banks, which, with the help of recently developed tele-transmission systems, put important orientation and basic data at the designers disposal, is a very recommendable initiative.

2.4. The efforts made by several water supply companies to come to a better exchange of ideas on a national and an international level are also to be stressed. The foundation of the IWSA, exactly 40 years ago, the continuous growth of this Association, and the encouraging perspectives to the future conform the necessity of co-operation between specialists across national borders. Thanks to the exertion of many pioneers, workshops, symposia and congresses have grown to meeting places of colleagues who are often confronted with identical problems, which may differ only in the secundary aspects. Discussions and mutual respect are most of the time additional steps which lead to a better evaluation of the task, helped by the available literature.

2.5. Thanks to the rapid evolution in the means of communication and transport, the existing installations can be visited and specific problems can be discussed with colleagues at the site in order to come to an optimal design.

2.6. It cannot be denied that our predecessors, be they managers or colleagues, must have anticipated the necessity of this methods, but the unpredictable growth of communication techniques has only recently offered new opportunities to our generation which, we are unmistakably sure of that, can be fully used to the benefit of elaborating new designs.

3. THE PRELIMINARY EXPLOITATION OF THE SITE

3.1. Due to the expansion of our cities, the maximum occupation of our territory by agriculture and to the continuous care and concern for the conservation of the ramaining landscape, the choice of the site for new installations requires more and more detailed prospection of the considered premises.

3.2. Within the European Community, one presently works at imposing legaly the so-called Environment Impact Assessment (EIA) for constructions which may drastically change the environment. To our opinion water suply companies mostly do not disturb the environment nor interfere with it in an ecologically unsound way. Nevertheless, a recent evolution can be felt towards severer conditions for exploitation and for changing the scenery. The location of a new plant will therefore no longer only be determined by financial or technical considerations regarding the exploitation only, but will also depend on the care taken for the landscape and the environment.
The necessary study of several alternatives for new projects has slowly become a normal obligation, an evolution which is going on, not without suspicion, since it may slow down needlessly the planned and often necessary urgent execution of a new project.

A positive evolution however in the draft of an environmental evaluation study might be the possibility to constructive contacts between water supply specialists and scientists of other disciplines, widening there view.

Nonetheless, contacts between water suply specialists and scientist of other disciplines in the course of the EIA-study, are always positive.
Team-work with civil engineers, chemists, biologists, agriculturists, geologists, geographers, geo-morphologists, even with historians, and paleonthologists is to many of us a new experience which, although time consuming, can be improving and constructive. Furthermore, these contacts may accelerate the approval of a new project.

3.3. Here too, the actual techniques and existing organisations have contributed to facilitate adequate solutions to be obtained :

- For large-scale projects, and whenever maps are not immediately at hand, we have now access to satillite photographs of the earth's surface which allow to obtain an overall survey of relief, vegetation, housing and occupation of the area concerned;

- The elaboration of a worldwide net of meteorological observation stations, coupled to data delivered by weather satellites, allow to better evaluate the climatological circumstances, the data concerning precipitation, etc. with the aid of detailed maps;

- Although, as far as prospection to be executed in well-known regions is concerned, the above-mentioned facilities are normally not used. Aerial photography remains an indispensable link in the reconnaissance of the area. By previously placing reference marks, e.g. red-white disks of only 0,5 m diameter, aerial photographs can be transformed in maps with the help of aerial photogrammetry techniques.
  Sophisticated, partially computerized machinery, very pricise maps of the concerned area even on a 1/1000 scale can be composed on the basis of a series of photographs. By adequate triangulation and altimetry, the maps can be integrated into the existing coordinate-system and the necessary contour lines can then be applied.

- To perform such precision measurements, it is obvious that high precision theodolites must be used, coupled to infrared telemeters. The balancing of the observations and the determination of the degree of precision of the surveys can be obtained in a minimum of time, thanks to existing software programmes which are based on the calculus of probability and on the error theory.

  The well known roundabout calculation and graphical iterations presently belong to the past.

- Specialized firms also offer facilities to draw directly the results of the topographical survey with the help of CAD-techniques and to have these result digitalized.
  Recent evolutions in drawing techniques, in which the composition of both the ink and the paper have undergone fundamental changes, give the engineer the disposal of multicoloured, unalterable, and time-resistant gloss on sensitive paper.
  By digitalizing the data, their manipulation via the screen of the computer is reduced to a simple and even amusing occupation.

- By using extremely sensitive film or UV-film, apart from the topographical data, important information concerning physical parametrs of the soil can also be obtained from the aerial photographs. Among others, high humidity zones, areas where the vegetation could be affected, can be detected and hidden structures or remnants of foundations can be found with great precision.

3.4. The above-mentioned possibilities however do not allow to obtain some knowledge regarding the geological structure of the subsoil which, in the case of water winning areas, is of the utmost importance. It is a usual procedure to consult geological maps and the results of formerly executed investigation borings.

Recently seismic tests, if necessary completed with gravimetric ones, may provide important information concerning possible discontinuities in water layers, faults in rock formations, or the presence of cavities. These tests demand important investments in apparatuses, considerable precision when installing the devices in the field, thorough know-how, and practical experience in order to make meaningful readings. These tests are an interesting and useful complement to the geological survey, so that they have recently made their appearance the world of water.

Partially thanks to the evolution in the possibilities offered by micro-cameras, cavities can be investigated through one or more boreholes and their co-ordinates can be calculated based on precise measurements.

3.5. - A preliminary soil-mechanical investigation is essential as a function of the desired location of the new design on the site, and of course to define the possible or most suitable foundation-system.

- The classical in situ-tests such as the performance of mechanical deep-soundings or investigation borings are already well known.

- Nevertheless more advanced techniques also find their way to the water supply companies.

- More accurate results can be obtained by carrying out deepsounding equiped with electric-ione resistance measuremtns and local lateral friction.

- The determination of the in-situ cohesion and of the angle of internal friction for clayey soils might be obtained with the help of vane-tests.

- Continious prelevation of undisturbed samples, intended to obtain quickly a visual image of the different ground-layers.

- The execution of permeability-tests-in-situ in sandy soils are indispensable when designing ground water catchements, in clayey soils however, pore-pressure measurements supply important information on the existence of artesian waterlayers.

- Minor soil movements, even in the deeper layers, now can be deduced form inclino-meter tests. These measurements necissitate the placement of special tubes in a previous borehole and th execution of previous reference measurements, before starting the ecavations. The highly precise results of the measurements can indicate important information about possible sliding surfaces in due time especially when huge excavations or refillments need to be carried out.

3.6. The processing of the previous soil-mechanical and geological survey requires the necessary specialisation, sophisticated measurement apparatuses, calculation techniques, and mathematical models, and also the possibility to carry out laboratory tests of the physical and mechanical properties of the ground layers. The collaboration between specialized institutes or firms with the water supply companies is therefore most obvious.

Although it is not yet generally introduced, the most recent evolution in carrying out studies of preliminary drafts and definite designs clearly indicate this way.

3.7. The former brief survey, mainly based on interrogation of local occupants of the area, on checking the foundation methods in the vicinity and inspecting the ground water level and the vegetation nevertheless remain valuable but can presently only be considered as interesting and neccessary completion or confirmation of the more scientific based survey of the site.

4. THE DESIGN

4.1. After consultation of the literature and discussion with colleagues, eventually after having brought a visit to comparable installations, and finally after examination of the measurements and tests on the very site, completed by results of laboratory tests, the definite draft can be started with.
Here also an evolution in the applied working method can be seen :

- in spite of the results of the preliminary study, the final draft for the design must be proposed after a mature consideration between the specialists of several disciplines.
The thorough knowledge and skill of each one of them is thereto a first requirement

- owing to the complexity of the problems posed, to the lasting paticularity of every water supply company, and to the concern to find the most adequate solutions thereto, both technical and financial, it is often considered to build a pilot installation. In spite of all kinds of theoretical considerations, the examination on a larger scale still remains an indispensable part of the preliminary study. Exchanging know-how in this matter on national or international scale, will help to generally minimize the cost as well as the time the tests will take.

- due to the growing energy awareness and to cost-effective demands imposed on every new construction, and as far as specific high-technological, hydraulical or aero-dynamical questions are concerned, contacts are often established with Technical Universities or with specialized Institutes or Research Centres. Mixing problems in raw-water reservoirs, influences of wind-action to water-towers not only after construction but especially during construction, flow pattern in clear water reservoirs, realimentation of water-layers, etc. are some of these complex problems.

4.2. The choice of materials determines in an important way the aspect, the design, the life, and sometimes even the manner in which the construction should be realized. Owing to the continuous increase of available new materials (as further commented on) a tendency originated to require from the suppliers that they dispose of the necessary know-how regarding the application of their own products. It happens not infrequently that their assertions are confirmed by the results of tests executed by their own laboratories or by the research division of Technical Universities. Such kwowledge concerning materials may allow the designer to make a better and more justified choice regarding the projects to be realiezed.

4.3. When designing the constructions, the architect nowadays is no longer limited to just work out an esthetic unity with hard-wearing materials.

Indeed, under the influence of a growing environmental consciousness, he is further confronted with requirements concerning a better integration of his construction into the environment and the scenery.

It is well known that this is not always as easy as it sounds and we are aware that consultations between engineers and environmental groups should take place in a more constructive and scientifically higher principled atmosphere.

4.4. In the course of the designing phase, obviously, due attention is given to the security of the construction, to its durability, and to an easier maintenance. The concern for a continious delivery of good drinking water is for the water supply of first importance. Protection of the treatment plant and the installation against natural disasters such as earthquakes, inundations, settlements, hurricanes, as well as against human destructions are more and more considered. Since this concern always leads to an increasing cost of the construction, more attention is given to economical considerations. The search for other cost-reducing factors has become therefore an absolute priority and for the future much progress will certainly be made in this matter, since improvements are already applied such as :

- a pursuit for further standardizations in working methods, building materials as well as in computations, on national and international scale, anables the contractor to reduce its prices;
- to design simplified and modulated constructions can influence considerably the construction-time and can reduce the chances that mistakes are been made;
- simplified maintenance enhances the constructions life and its performances.

A general tendancy towards the application of prefab-materials, and of selective and durable materials is therefore clearly showing.

5. THE ACTUAL STUDY

5.1. Here also, important evolution in the calculations is the tendency towards standardization :

- the drafting of national or even international standards concerning the several load problems, including admitted tensions and deformations and concerning the security coefficients to be respected, put a basis at the disposal of the engineer or the engineering bureau allowing them to obtain, in a simple way, a survey of stability studies to be executed;
- owing to an increased standardization in the calculation systems, it has become much easier and more surveyable to check the calculations of third engineering bureaus;
- the development in normalization of available drawings and drawing techniques, for which software programmes are conceived on an international scale, is similar to this evolution.

5.2. To be able to dispose of high-qualified calculation programmes, gives rise to a tendency to sophisticate also the calculations and to better evaluate the possible combinations of load problems.

Apart from being able to perform iterative calculations in a minimum of time applying finite-elements methods can offer very often acceptable solutions when exact calculations prove to be too laborious.

5.3. Due to the extensiveness of the calculations, a visualizing of the draft or part of it proves to be a welcome or even indispensable help.
Although the CAD-techniques are still not entirely integrated when it comes to drawing new constructions, there is a tendency of using these new facilities more frequently in water supply companies.

Important exertions have been made in the training of high-qualified pesonnel and staff and preparations are being made in digitalizing existing plans and details.

6. THE BEGINNING OF A NEW CONSTRUCTION : THE FOUNDATION AND THE GROUNDWORK

6.1. Besides the classical foundation methods such as shallow foundation and deep-foundations, presently modern foundation techniques are being applied in the water suppply sector. The evolution of the techniques created the possibility of applying more adequate foundation systems :

- soils with a low bearing capacity can now be consolidated in an accelerated way by applying vertical drainages, eventually coupled to a pre-load. For sandy soils with peat-layers, excellent results can be obtained by dynamic consolidation -the so called Ménard-method. Heavy weights falling down from heights up to 20 m are originating shock waves in the layers by which pore water is expelled and granular strain is increased.
- in order to increase the bearing capacity and the shear-strength of sandy soils, soil displacement is applied by using the vibro-flotation technique, with which gravel and sand piles are formed in the less resistant layers.
- the consolidation or stabilisation of more impervious soils as well as for stabilisation of fissurated rock-formations a better stability might be obtained by injecting groutings based on concrete, polymers or resins. Recent developments in chemistry are still creating new possibilities.

6.2. The construction of impervious walls, formerly mainly obtained by driving sheet piles, is presently carried out much more economically by forming cement-bentonite walls. Impervious screens going to a depth of 30 metres are no longer exceptions.

6.3. Deep excavations, to be excecuted in a limited space, taking into account nearby existing constructions, have more and more becme an obligation, imposed by the authorities. Here also the recently developed deep wall techniques, eventually coupled to the use of ground anchors offer possible solutions.

6.4. Lowering the ground water is an absolute necessity to the construction of a new building or foundation. But this may cause ground settlements which are anyway undesirable.

The technique of feeding the surrounding phreatic level with the drained water from the site offers the designer the opportunity of avoiding a great number of problems, and not a least with neighbouring inhabitants. Since this technique requires a special treatment of the re-injected water as well as an advanced knowledge of the soil behviour, it is to be recommended to leave the application of the method to a specialized firm.

6.5. The draining of the ground by providing ground drains is a well-known and durable method, but the application of geo-textiles, woven or non woven offer presently far more possibilities. For both vertical and horizontal drains, their use increases daily.

Recently geotextiles with high shear strength are applied. Due to their characteristics of permeability to water and their soil-retaining capability, are the stabilisation of slopes, by preventing the formation of failure surfaces, and the reduction of the shear forces between the soil particles, prove to be the most important range of applications.

6.6. Stable backfill or ground heightenings can only be assured by constructing flat slopes. Steepish slopes can only be realized if expensive sheetpilings are used. Esthetic solutions may presently also be obtained by applying reinforced-soil techniques combined with prefab earth retaining walls. Although this technique is nowadays mainly used for the construction of roads and bridges, interesting applications may be found in the field of water supply.

7. THE ACTUAL CONSTRUCTION

The evolution in the realization of a new construction can be subdivised in three main trends :

- the evolution of the working methods;
- the evolution of the machinery;
- the evolution of building materials.

The following paragraphs will treat some specific evolutions, although each new evolution may as well be called a synthesis of all evolutions within the above-mentioned topics.

7.1. Evolution of the Working Methods

- As most important factors which determine the working methods can be indicated undoubtedly : the hourly wages and the cost of the available forms of energy;

- The upward trend in hourly wages tends towards making savings such as :

  - modulated designs and standardization;
  - accelerated training and higher specialized staff;
  - increased automation;
  - increased production through the luse of sophisticated machinery.

- The increase of the production capacity of the machinery has undoubiedly stimulated the protection of the skilled worker.

- The drafting of detailed work planning before starting the works has now become a necessity as to allow the building contractor to maintain his competitiveness.

- An accurate recording of individual performances and the execution of detailed post-calculations are now generally applied.

- More and more often, the main contractor entrusts parts of his work to specialized sub-contractors, a system which may present advantages as well as disadvantages to the customer.

- Strong competition on the construction market resulted in the specifications of the works to be more carefully read and in the frequent intervention or jurists called upon to judge in mostly financial matters. This stimultes the client to carefully draft the specifications of the works.

  Here also, there is a trend to standardize the specifications and to elaborate these by mutual ararangement as well as to standardize the execution methods. A closer collaboration of water supply companies and standardization institutes will prove to be a priority in the future.

7.2. Evolution of Machinery for the Building Site

The existence and supply of new materials as well as the demand for adapted working methods has provoked a real revolution in the available machinery for the building site.
The regularly and most succesfully organised international exibitions of this machinery is the most obvious proof of the continious evolution in this field.
The most important and determinating option factors for the designer seem to be :

- scale enlargement as well as scale reduction;

- mobility and durability;

- safety and comfort for the conductor;

- minimum energy consumption.

To run op the evolution in permanent and travelling cranes in high and deep-loaders, in bull-dozers, dumpers, retro-shovels, etc. would certainly lead us to far. However further evolution might be expected in he coming years, especially in computarisation and automatisation of the steering equipments, the use of alternative energy and in the application of robots.

7.3. Evolution and innovation in the building materials.

This evolution is for the designer obviously the most spectacular callenge. He, at least, is considered to be aware of the latest innovation in order to be able to incorporate the new technology in his projects and to achieve the right balance between cost and quality standards. Due to the magnitude of the evolution in the building materials, the different kind of materials are split up according to their particular applications.

7.3.1. Ceramics

- Due to a more accurate knowledge of the existing clays and of the possible additives, due to the optimization of the baking and drying process, a further improvement of the price-quality ratio could be otbained especially in the fabrication of bricks, facing bricks and paving bricks.

- Thanks to the evolution in colouring techniques, in hardening the overglaze and in increasing the wear-resistance, a remarkable improvement in the quality of glazed stoneware would be noted.

7.3.2. Glass-production

- Complementary to the continuing improvement of the application in glass industry, such as the fabrication of double glazing, armoured glazing, wired glass and bulletproof glass, foamglass finds a growing application as insulation-material, due to its durability and his imperviousness to moisture.

- Glass-fibers, on behalf of its recent application in optics, has perhaps importance advantages in pre-stress techniques. Although some applications on full size are known, a lot of reserach on the behaviour-versus time of the fibers has to be done.

7.3.3. Wood or timber

- Thanks to the evolution in synthetic glues, polymers, resins, epoxies, wood-protecting paints and to the continious improvement of the woodwork-machinery, carpentry obtained a new élan.

- durable formwork in hardboard or multiplex allow multiple reuse and in cost-saving;

- plywood or bonded wood is used, in combination with steel-profiles and edges, as shuttering and high-quality formwork and in pre-fab techniques : thanks to weather-proofing and glueing frequent re-use is garanteed.

- wood chips, shavings and wood flour are no longer condemned to be burned, but it can actually be used in insulations-materials.

7.3.4. Concrete and concrete-products

- Due to the strict requirements in cones-resistance, durability, water-proofing as well as in the outlook of concrete, more interest has to be paid to the composition of the concrete on a scientific basis.

- In function of the required result, water-content, the composition of the granulates and the quantity and quality of the cement are carefully dosed, generally based on previous research in the laboratory.

- Compressive strength and porosity are statistically determined by an extended sampling and examination on the site as well as in the laboratory.

- Recent normalisation and regulation are helpfull in order to obtain good quality.

- The research and development on grouts on basis of epoxy-resins has known a flourishing period; recent evolution however shows more and more specified applications, such as the use in renovations, in restoration work and in the formation of special moulds.

  Although one can say that these epoxy-mortars or grouts have become almost indispensible in the realisation of a construction : for instance in the reparation of holes in concrete structures, in filling the perforations in concrete, in concreting anchorings, in levelling floors, in founding machinery etc.

- The cellular concrete or light weight concrete is more and more applied as self-substaining insulation;

- The prefab-concrete, formed in the workshop, independent from the weather conditions, and manufactured under a severe controle, is generally of high quality and is taking a still growing share of the market. A garanteed quality, size-holding and simplicity in. application are of course the main trumps.

7.3.5. Steel and steel-products

- on behalf of the classical applications of welded steel, reinforcing steel or steel-profiles, other steelproducts are used in special applications, in order to reduce cost and improve the security of a construction :

  - welded steelnets are simplifying the reinforcement of concrete;

  - reinforcing steel is cut, formed and bound automatically, and this more and more computerguided;

  - dilatation joints and working joints are frequently formed by steel-plates;

  - previous concreting of anchorage-profiles (for machinery, trolleys etc.) is often preferable to anchorage by screw-bolts after hardening of the concrete;

- the connection of reinforcing steel by using overlappings is still widely used, although the technique of screwed or coupling sleeves is recently more and more applied;

- the protection of the steel against corrosion has always been the main target for the engineer as well as for the architect. Thanks to the use of specialised paints and coatings the aim can now be reached in an economical way. Even for the protection of pre-stressed steel-wires interesting applications could be forescen;

- steelfibers, taking on shear-stresses in concrete slabs, are used in special circumstances, and new applications or still growing;

- woven steelnets might be applicated as formwork in case of complex forms or as temporary joint;

- especially thanks to a favourable price-quality ratio, more and more stainless-steel is applied in anchorages and linings in contact with potable chlorinated water.

7.3.6. Bitumous products

- Thanks to research and development, by combining it with other materials such as rubber, plastics, slate flakes, etc. bitumen is grown from a waste product of the petroleum destillation to a valuable product with specific applications :

  - as fixation of lime stone in embankments and under-water slopes;

  - as a component of asphalt-concrete pavements;

  - as a component of impervious reinforced bitumous membranes in raw-water reservoir.

7.3.7. Stone

Due to the growing cost of natural stone, only in special conditions stone could be applied although generally its quality is outstanding.

7.3.8. Composites and other materials

Although recent evolutions must be situated in mechanical engineering, in the construction of aeroplanes and in the spacecrafts, composites will certainly find their way to civil engineering constructions in the near future.

- High-build rubbers are applied in dilatation-joints, in foundations of bridges, in expansion-joints, and in vibration-free foundations of machinery.

- Epoxy-coatings and powder-coatings are generally applied in the battle against corrosion. Sophisticated spray-techniques and emerging of the construction parts in a fluidised bed of melted powder-coating can now garanty an over-all, durable and non-toxic protection of the steel.

7.3.9. Materials for pipes and mains

Interesting developments in pipe-materials, can be noted down, however a more detailed description is outside our scope.

8. REPAIRING - RENOVATION - DEMOLITION

8.1. During construction and certainly after the construction has been taken into service, small repairs will become necessary, whatever the care taken for it.
The most obvious imperatives for the operator are the reduction as far as possible of the repairing time, of nuisance and of the total cost. Nevertheless the reparation always must be durable.
New technologies are again helpfull in this matter :

- cement, coarse-sand and fine gravel in combination with polymeres and epoxies will form and ideal mortar for reparation of concrete structures, for fastening anchorages, for protecting rusted steel against further corrosion and specialy for relining aquaduct and mains;

- the actual possibility of dry transport of the granulates by compressed air is an advanced technique which allows the transport over large distances without segregation of the components;

- swell-seals and poly-urethanes which are forming polymers in wet circumstances, will form the ideal barrier for leakage.

8.2. - The bearing capacity of reinforced concrete beams can be increased by applying supplementary outward steel-reinforcement;

- Making holes vibrationless by using diamant-bores might be of great help and can offer interesting possibilities when existing plants had to be extended or adapted;

- Under-water techniques, performed by skilled divers, have merely become a absolute necessity in renovation and inspection of installations when taking out of service could not be considered.

8.3. - Demolition is no longer simular to uncontroled use of explosives, unwanted vibrations and deterioration of installations into service.
High pressure water-jets, eventually in combination with diamant-powder or controled fusion welding anable to cut reinforced concrete structures in a minimum of time and without causing damage to neighbouring construction.
This new techniques, ecologically sound, are still in full development and only results of experiments on a small scale are yet available although a lot of interesting research is already achieved.

- To deal with the use of explosives judiciously can however be very helpfull in the demolition of large structures. By applying the correct strength of the successive explosions, by determinating exactly the intervals, a demolition might remain under controle. In some cases even the maximum size of the broken stone can be determinated previously.

- Further evolution is shearing machines and refraction-machines, sieves and grading machines will allow further reducing the size of the waste.
Important research is done on possible re-use of broken waste and some experiences on preparation of concrete gave successfull results.
The uncontroled growth of the waste-mountain will, in the near future, finanally be stopped and new applications will be found by using the actual waste.

9. CONCLUSION

The actual evolution as well as the expected evolution in civil engineering can be of great help to the realisation of the IWSA-endeavour Drinking Water for manking.
By constructive group-work between colleagues, specialists manufactures and contractors the search for succesfull application of classical, as well as new, techniques in developping countries must be continued.

Although the challenge for the 21ste century will only be obtained by an advanced and fundamental professional training of our engineers and scientists, by extended research and development, by exchanging of ideas, knowledge and experiences on national and international basis, by study of literature of advanced technical magazines and last but not least by common sense and a good deal of enthousiasm.

By drawing back to the enthousiasm of our predecessors, with the actual possibilities of materials and techniques, we believe the future will enable us to succeed.

COUNTERMEASURES FOR THE EARTHQUAKE-PROOF IMPROVEMENT OF WATER SUPPLY PIPELINES

Hiroshi MIYAMOTO, Sadamune HOJO, Toshiyuki IWAMOTO
Pipe Research Dept., Kubota Ltd., Ohama-cho
2-chome, Amagasaki-shi, Hyogo, Japan

ABSTRACT

This paper deals with the following subjects for improvement of earthquake-proof characteristics concerning water supply pipelines in the year 2000.

1. Damage to water supply pipelines due to earthquakes in the past.

2. Technical problems for the earthquake-proof improvement of water supply pipelines.

3. Proposal for countermeasures for earthquake-proof improvement of water supply pipelines.

KEYWORDS:

Water supply pipelines, Earthquake-proof measures, Damage to pipelines, Research on earthquake-proof Characteristics, Earthquake observation, Earthquake-proof design countermeasures for earthquake damage.

INTRODUCTION

It is impossible to eliminate the prospect of an earthquake occurring through the employment of some geophysical mechanism. Damage resulting from an earthquake is occurring somewhere in the world even as you are reading this paper. While studies are being advanced regarding earthquake-proof structures on the ground, such studies concerning underground structures have only just been started. Among others, studies and countermeasures are far behind as regards the buried pipelines of water supply, sewage and gas.

In this paper, the authors describe the damage to water supply pipelines due to past earthquakes. They identify technical problems for the improvement of anti-seismic character of pipelines and proposals for carrying out the improvements.

Damage to Water Supply Pipeline Resulting from Past Earthquakes

Descriptions are given below concerning damage to water supply pipelines caused by major earthquakes in Japan and overseas.

1. San Fernando Earthquake The San Fernando Earthquake with a magnitude of 6.7 took place on Feb. 9, 1971 causing considerable damage to high bridges, hospitals and buildings in the northern part of Los Angeles in the U.S.

It also destroyed a large number of pipelines utilized for water, gas and sewage.

Average rate of damage to pipelines in the areas with severe damage were 1.0 No./km for water supply pipes (mostly of gray iron), 0.9 No./km for gas pipes (steel pipe, welded joints) and 0.6 No./km for sewage pipe (clay pipe).[1),2)]

2. Mexican Earthquake Buildings and water supply pipelines in Mexico City, the largest urbanized area in Mexico, were severely damaged by a big earthquake with a magnitude of 8.1 with its epicenter about 350 km from the city on September 19, 1985. Figure 1 shows sites of the damaged water supply pipelines. Water supply to about 40 percent of total population was interrupted and the social life of the people residing in the city was seriously hampered. Average rate of damage to the water supply pipelines (mostly of asbestos cement or concrete) was 0.1 No./km.[3)]

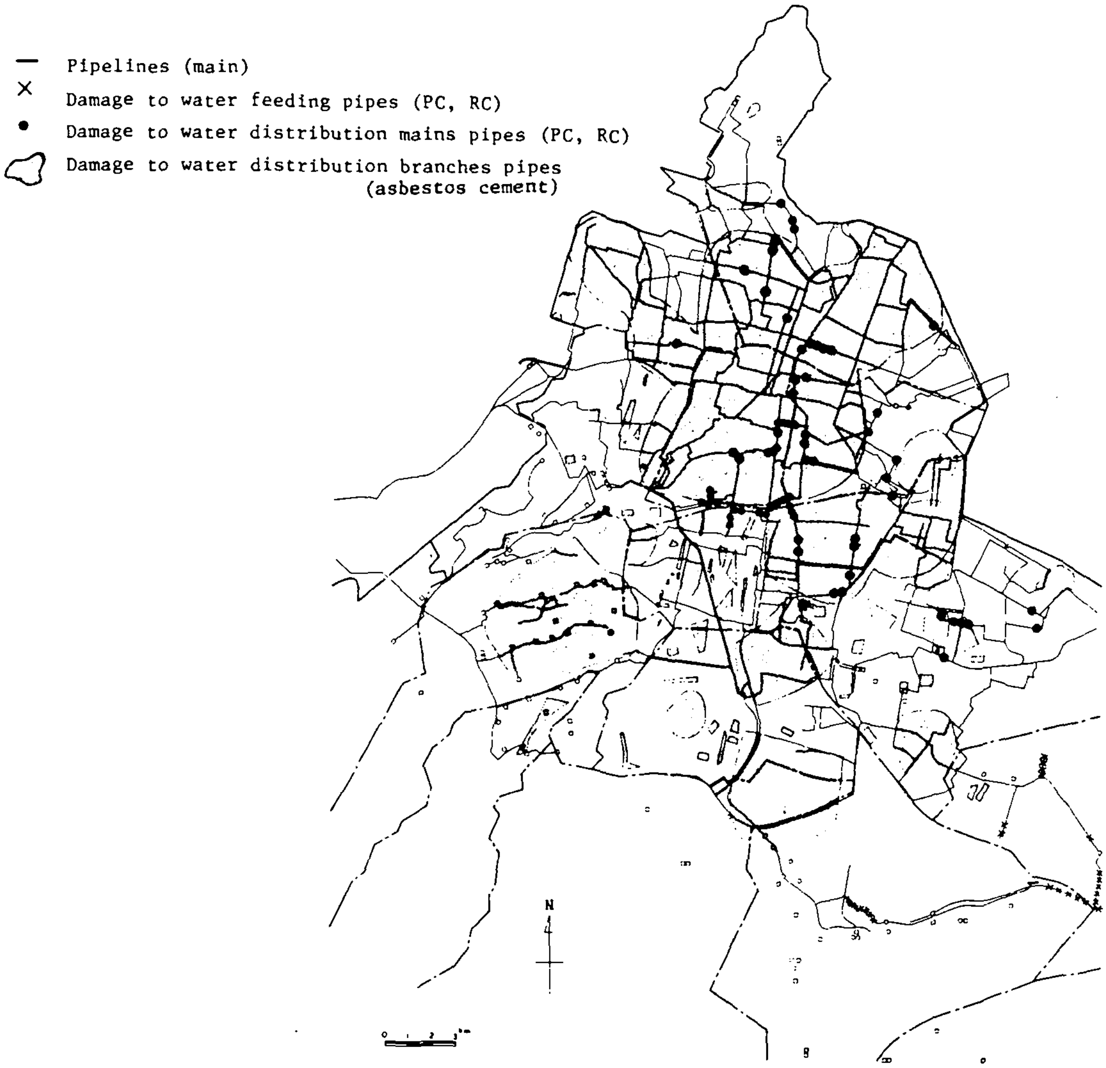
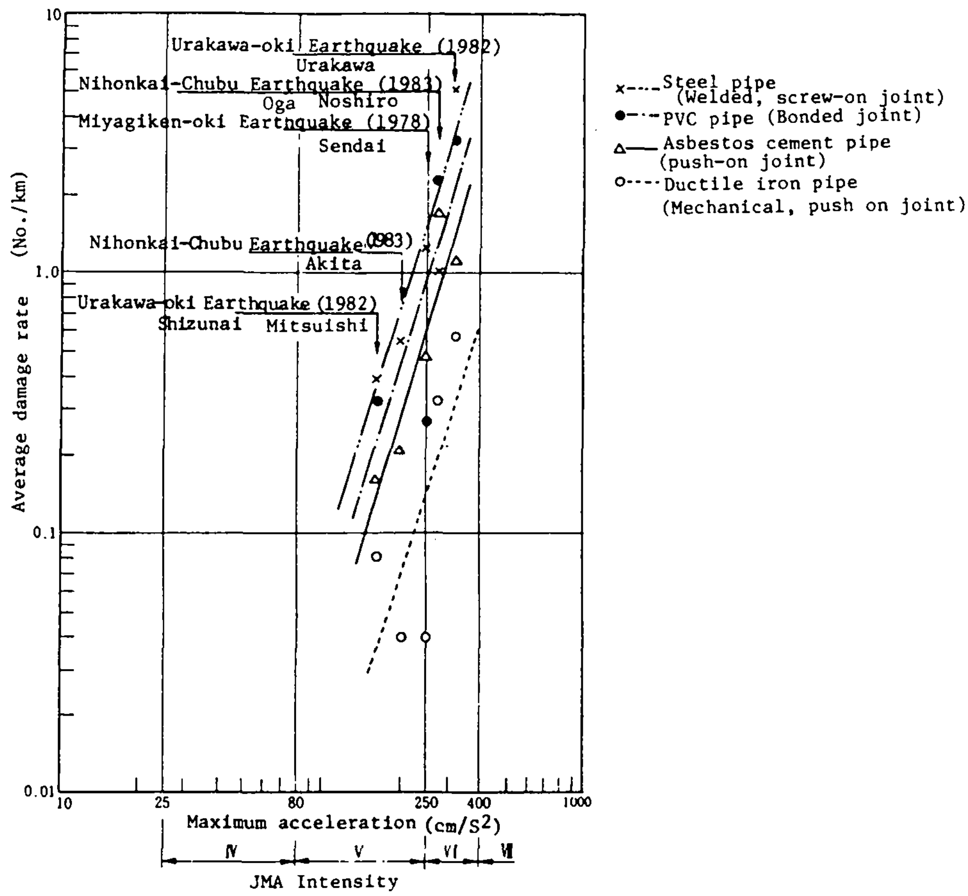


Fig. 1 Damage to water supply pipelines by the Mexican Earthquake in 1985 (Mexico City)

3. Earthquakes in Japan A vast amount of damage to buildings, water and gas supply pipelines occurred in Japan as a result of the Kanto Earthquake in 1923. The average damage rate to grey iron pipelines in Tokyo city was 1.00 No./km. As a result of the Kanto Earthquake, great advances have been made regarding technology for earthquake resistant building, which is nearly complete today.

Figure 1 shown average damage rate to water supply pipelines of steel, PVC, asbestos cement and ductile iron caused by the earthquakes of "Miyagiken-oki" (1978)[4], "Urakawa-oki" (1982)[5] and "Nihonkai-Chubu" (1983)[6], which occurred over the past ten years. As no significant reduction in damage is seen, no exaggerated to say that the study and technology on earthquake-proof buried pipelines are far behind those of structures above ground.



Note: Regression equation

Steel pipe : $ys = 7.0607 \times 10^{-9} \times A^{3.445} (r = 0.923)$

PVC pipe : $yv = 6.1674 \times 10^{-9} \times A^{3.412} (r = 0.763)$

Asbestos pipe : $ya = 2.5782 \times 10^{-9} \times A^{3.491} (r = 0.910)$

Ductile iron pipe : $yd = 2.8625 \times 10^{-9} \times A^{3.200} (r = 0.700)$

y : Average damage rate (No./km)

A : Maximum acceleration (cm/s^2)

Fig. 2 Relationship between earthquake intensity and average damage rate to pipelines.

Technical Problems for the Earthquake-proof Improvement of Water Supply Pipelines

The water supply is one of the most fundamental facilities for maintaining the lives of citizens and urban functions. Measures for minimizing damage due to earthquakes should be sufficiently taken in order to maintain an adequate water supply no matter what the size of an institution. The counter-measures of pipelines is especially essential to provide an adequate supply of water for maintaining the lives of a city population as a lifeline.

The technical problems below are for improving the earthquake-proof characteristics for water supply pipelines toward the 21th century:

(1) Investigation and research of the behavior and mechanism of the ground and pipelines during earthquakes

Observations of behavior during earthquakes are the basis of anti-seismic research. The observing for soft ground and liquefaction area is of particular importance, where pipeline movement would be much more severe than in other types of ground. An effective design technique must be developed to improve on anti-seismic characteristics by observations, investigation of damage and as a result of the following.

(2) Investigation of damage to pipelines due to earthquakes

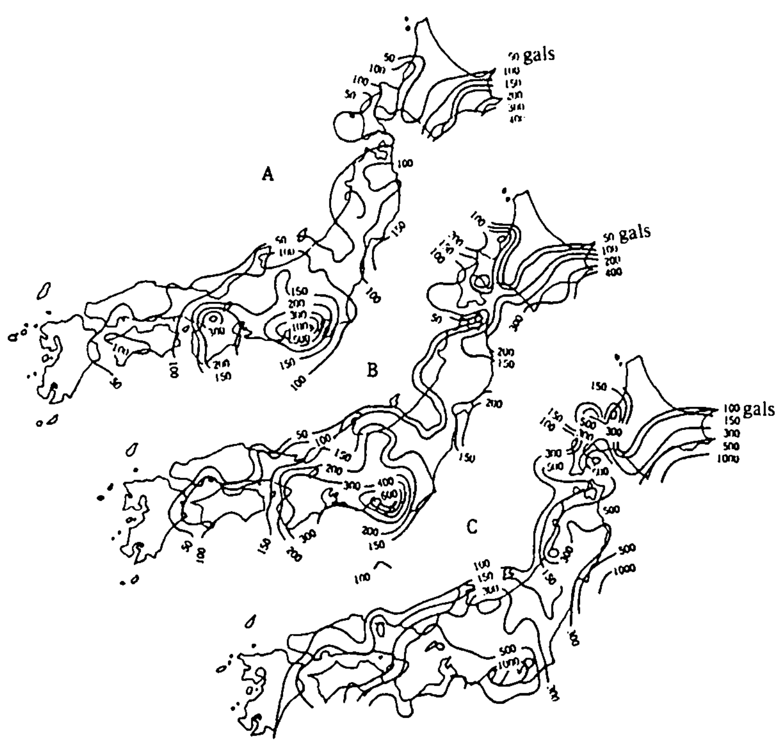
Water supply engineers should investigate damage to pipelines resulting from earthquakes immediately when they occur. It is important to reflect on the results so as to make improvements on earthquake-proof design and construction of pipelines.

(3) Study on the prediction of earthquake motion

Technology must be established and data must be collected to estimate the extent of earthquake motion that will be experienced in an area where the anti-seismic characteristics in studied for newly installed or existing pipelines in the period during when the function of the pipeline is expected to be maintained (As an example, for 100 years). Figure 3 shows an example in Japan for reference[7].

(4) Study and development of improved anti-seismic character of pipeline materials and joint structures

Tensile, compression and bending tests must be conducted with actual size pipelines to establish acceptable design of joint structures and fitting pipes as a bent portion with basic data taken from the above studies.



A = for 75 years

B = for 100 years

C = for 200 years

Fig. 3 An example of distribution of limited acceleration of earthquake in Japan

Studies are also required regarding the temporary recovery and repair of damaged pipelines as described below in such cases where sufficient improvement of anti-seismic character is not possible for economic reasons and possible damages are anticipated regarding the pipelines.

(1) Development of backup systems for pipelines by dispersion, partition and duplication

Development of studies are necessary concerning optimum partition technique and low cost emergency valves for these systems to work satisfactorily. It is also important to exactly map the portions of the pipelines throughout the city.

(2) Development of techniques for selection of optimum routes to be restored

Technical development is necessary beforehand to make the strategic simulation to evaluate the probability that damage will occur in particular areas and determine the most effective routes for recovery using probabilistic calculation techniques. Pipes, valves and other necessary materials may be secured for recovery based on the study.

(3) Development of earthquake-proof water tanks

Tanks for emergency water supply must be installed in areas where the earthquake-proof pipelines cannot be installed or access of emergency water supply trucks cannot be expected due to damaged roads. Low cost and simple water tanks must be developed.

Although we have also described recovery from damage to pipelines, it is most important to improve the anti-seismic character of pipelines in order to prevent the damage. The authors are conducting observations of behaviors of pipelines during earthquake as a basis of the earthquake-proof improvement studies. One of these observations in Hachinohe city in Japan is described below together with a part of results for reference.

Figure 4 shows an example of observations with ductile iron pipe (D = ϕ1500 mm). Figure 5 shows an example of recorded waveforms of the ground and pipelines. The relationships between the ground strain, pipe strain and expansion-contraction at joint for this record are shown in Figure 6. Figure 7 shows the relationship between the ground strain and the velocity amplitudes of the ground.

The several findings will be obtained from the above as follows:[8)∿11)]

(1) The expansion-contraction at joint (e) is given by Eq. (1).

$$e = \varepsilon \times \ell \qquad (1)$$

where, ε : Ground strain
ℓ : Pipe length

(2) The pipe strain (ε_p) is given Eq. (2).

$$\varepsilon_p = \frac{\pi \cdot D \cdot \ell \cdot f}{2A_o \cdot E}$$

where, D : Outer diameter of pipe
f : frictional force between pipe and the ground
A : cross section of pipe
E : Young's modulus of pipe

(3) The ground strain (ε) is given by Eq. (3). For earthquakes with epicenters of medium and long distances, it is generated by Raleigh's wave (surface wave) reflecting the relatively deep ground structure at about 400 m under the ground's surface.

$$\varepsilon = \frac{v}{V} \qquad (3)$$

where, v : Ground velocity amplitude
V : Propagation velocity of earthquake wave

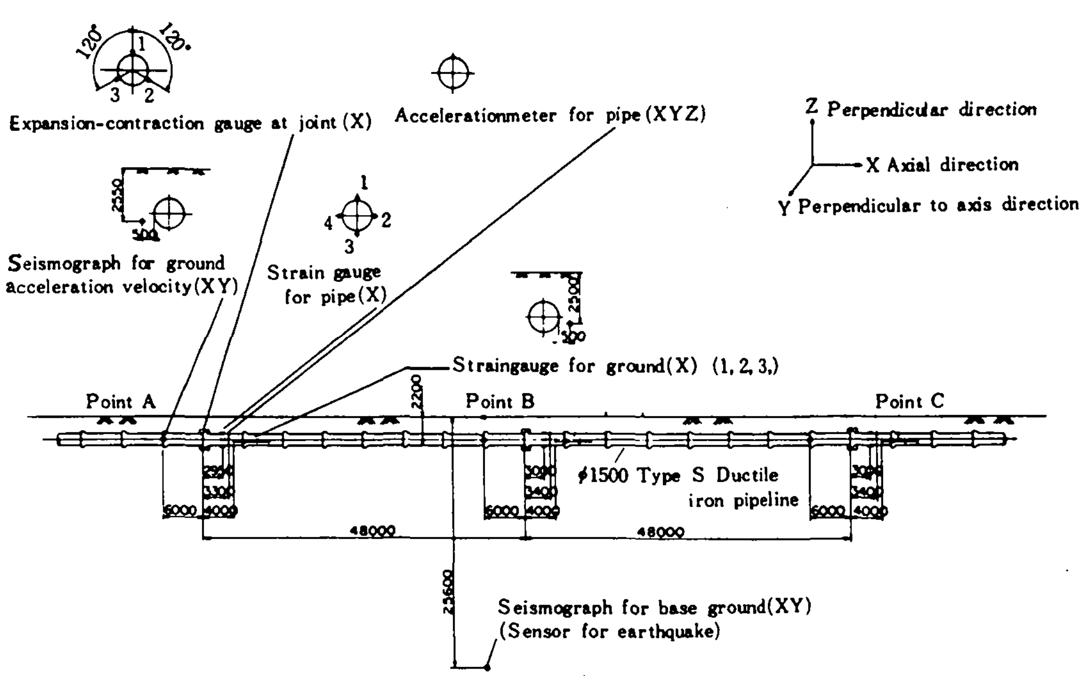


Fig. 4 Kansen observation station (Hachinohe city).

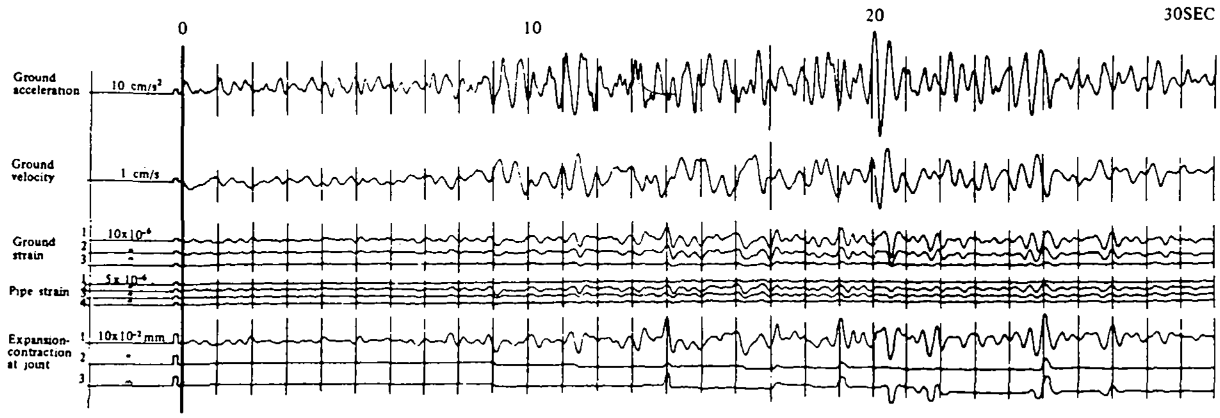


Fig. 5 Waveforms recorded at Kansen Observatory (Miyagiken-oki Earthquake, 1978)

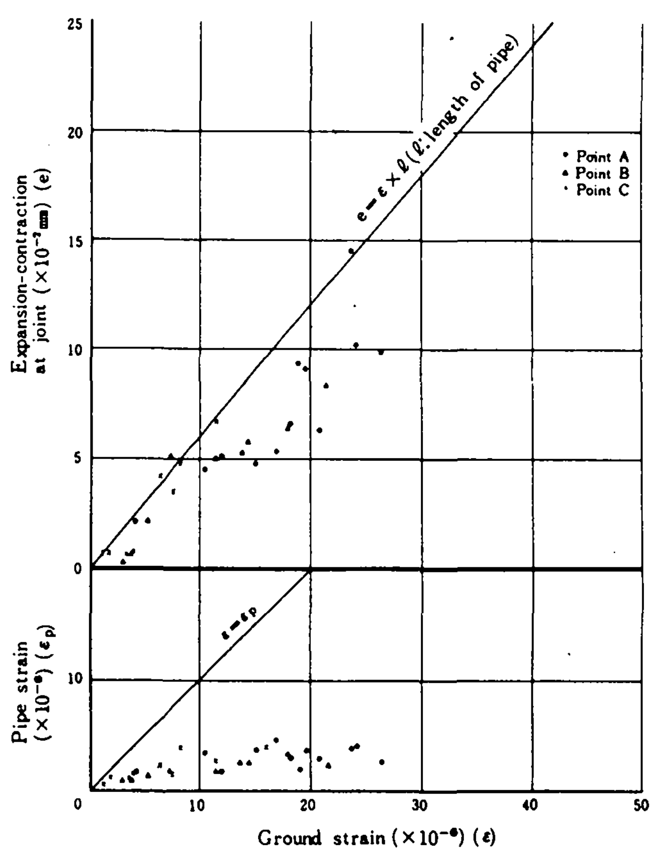


Fig. 6 Relationship between ground strain, pipe strain of pipeline and expansion-contraction at joint (Miyagiken-oki Earthquake, 1978, Kansen Observatory)

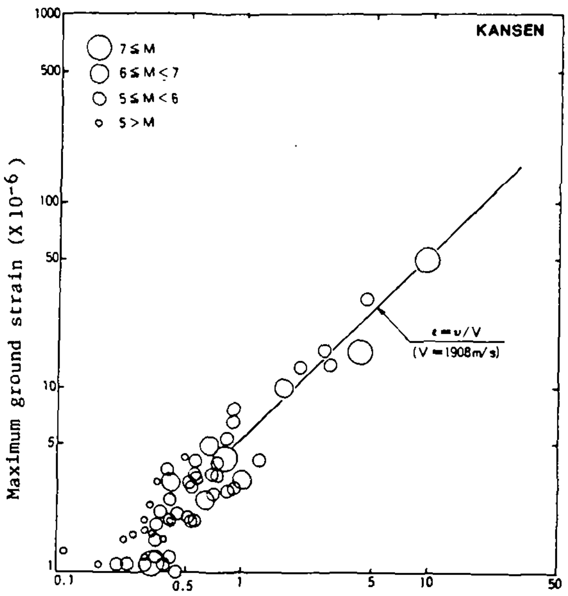


Fig. 7-1 Relationship between maximum ground velocity amplitude and maximum ground strain (Kansen Observatory)

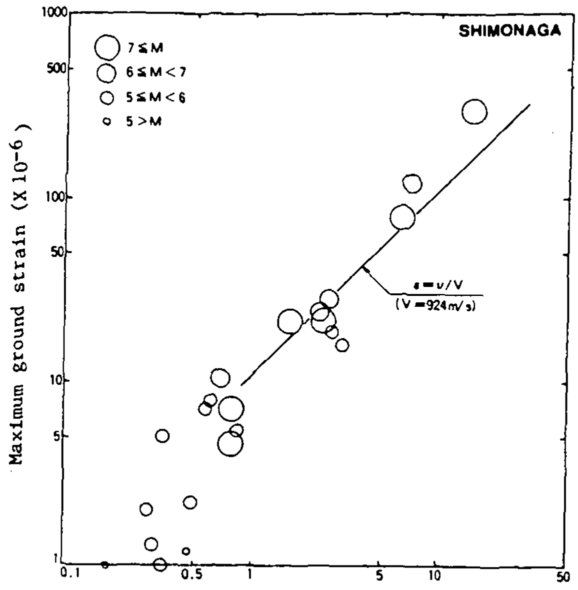


Fig. 7-2 Relationship between maximum ground velocity amplitude and maximum ground strain (Shimonaga Observatory)[10]

The above figures present recorded data up to seismic intensity = IV. Data for seismic intensity = V or higher must be collected.

Proposal for Countermeasures for Earthquake-proof Improvement of Water Supply Pipelines

As stated above, the study has been just begun on the improvement of anti-seismic characteristics of water supply pipelines. However, immediate measures must be taken since earthquakes are occurring at someplace in the world almost every minute of the day. The authors propose a measure for the improved one of the anti-seismic character of water supply pipelines below.

Water supply pipelines in Japan employ pipes of grey iron, ductile iron, steel, PVC, asbestos, PC and concrete with a variety of joints, including rubber, bonded, screw-on and welded joints. A plan for the improvement of earthquake-proof pipelines is proposed here for most commonly used grey iron and ductile iron pipes as an example.

(1) Rigid structure pipeline (pipelines in the past)

Pipelines with a rigid structure are composed of pipes of grey iron with low elongation and joints with a small expansion-contraction and low flexibility, such as flange type and socket and spigot joints as shown in Fig. 8. This type of pipeline was most severely damaged among grey iron pipes by big earthquakes in Japan and abroad, including the St. Fernando, Kanto, and Miyagiken-oki Earthquakes. In addition to the reason that they have been deteriorated due to being buried for a long period of time, one of causes may be the lack of proper provisions for earthquakes in the structure of the pipelines. As these pipelines are joined as one unit at the joints and designed to bear the deforming forces of the ground with the strength and ductility of pipe materials, which have their intrinsic limitations.

(2) Flexible structure pipeline (Current pipeline)

The flexible structure pipeline consists of ductile iron with high ductility and mechanical or push-on type joints having high expandability, contrastability and flexibility as shown in Fig. 9. This type of pipeline has the configuration that can follow the displacement of the ground caused by an earthquake settlement of soft ground or ground movement without generating any remarkable stress at the joints. Therefore, no damage was found on pipes and joints of this configuration due to the Miyagiken-oki and Urakawa-Oki Earthquakes showed very little damage. Pipelines consisting of ductile iron pipes and flexible joints are sufficiently earthquake-proof against medium intensity earthquakes and if on favorable ground conditions, against big earthquakes. The superiority of the flexible structure pipelines over rigid structure pipelines is clearly shown by the above-described results of the damage rates of pipes by earthquakes in the past and the results from earthquake observations using ductile iron pipes.

(3) Chain structure pipelines (Future pipelines)

As the above-mentioned pipeline structures have not been equipped with a mechanism of anti slip-out at joints, some concern still remains regarding its integrity where ground conditions unfavorable or where it is difficult to forecast ground movements, such as faults, cracking and liquefaction under strong earthquakes. There are also requests for sufficient emergency water supply for households and fire-fighting even though current pipelines are considered to be earthquake-proof, and requests for sufficiently safe major pipelines to withstand earthquakes. The chain structure pipeline is thought to be capable of meeting these requirements. This type of pipeline has a structure that can freely follow bending and expansion-contraction at joint like a chain but will never break. It incorporates the advantages of the present flexible structure to the highest extent to minimize the stress generated in the pipeline and to follow the movement of soil during as earthquake without allowing the joints to become disconnected as can be seen in Fig. 10. Fig. 11 shows a plan for earthquake-proof joint to meet above these requirements. The joint has functions which have sufficient capability of expansion-contraction and are equipped with a mechanism for anti slip-out.

The technical problems to be solved toward the 21th century and a plan for improved earthquake-proof characteristics of pipelines was described above for most commonly used grey iron and ductile iron pipes given as an example. The authors would be happy if this paper is of some value in minimizing damage to water supply pipelines due to earthquakes.

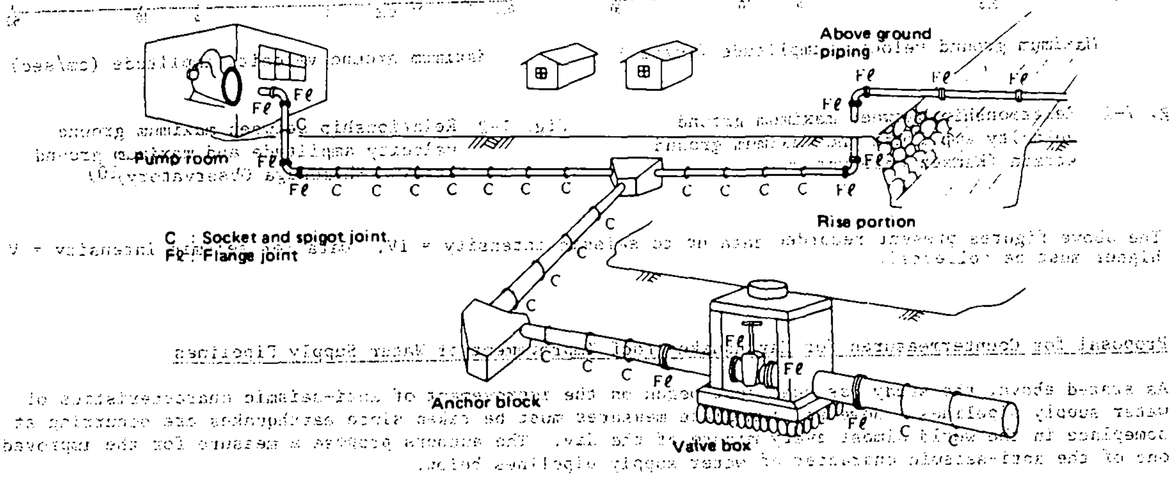


Fig. 8 Rigid structure pipelines (Pipelines in the past)

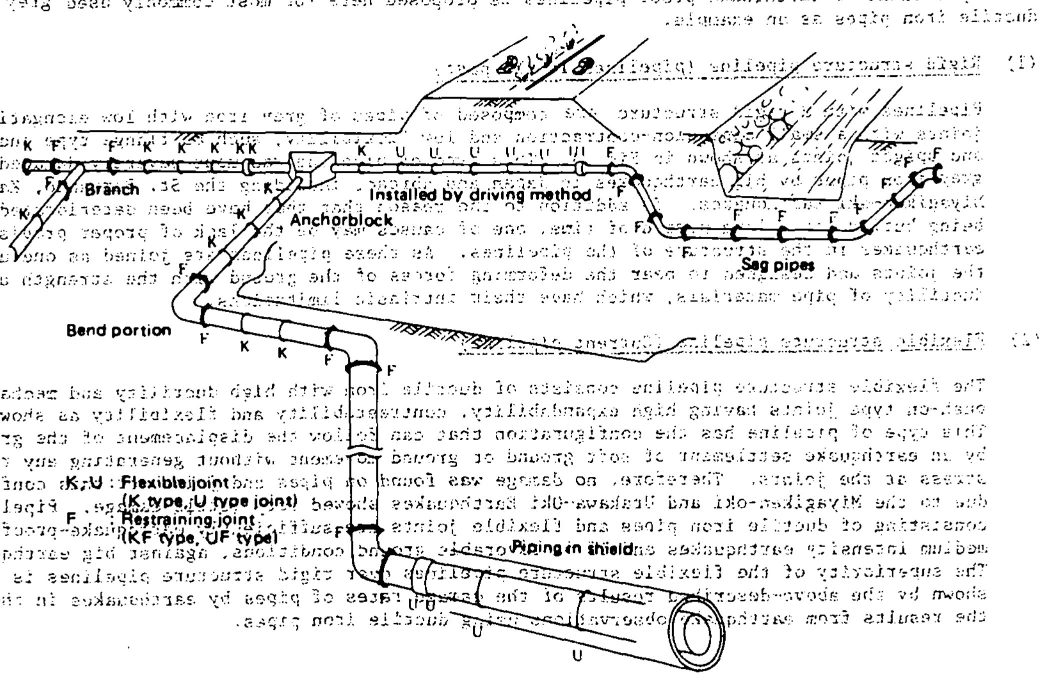
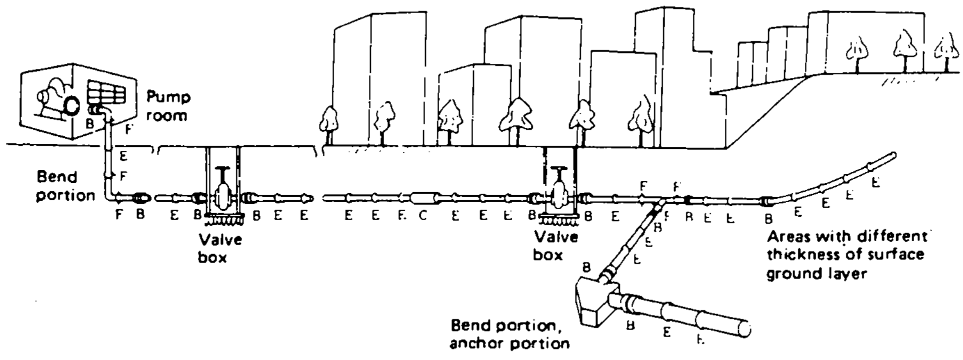


Fig. 9 Flexible structure pipelines (Pipelines of the present)



E : Chain type joints
B : Large angle flexible type joint
C : Special chain type joints
F : Rigid type joint (KF type, UF type)

Fig. 10 Chain structure pipelines (Pipelines in the future)

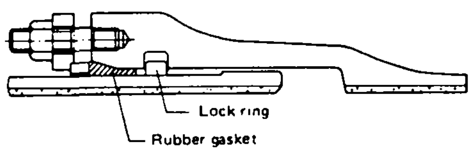


Fig. 11 Plan for earthquake-proof joint (chain type joint)

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SESSION 5

SEANCE 5

Chairman
Président Prof. dr. N. TAMBO

- Application of Stochastic LP Model on the Optimal Design of the Water Treatment Facilities

  Application du modèle stochastique LP à la conception optimale d'installations d'épuration

  Kung Cheh Li, Ming Yang Wu

- Membrane and Biotechnology, the 90's Method of Producing Drinking Water

  Biotechnologies et ultrafiltration : la méthode de production d'eau pour les années 1990

  O. J. Olsen

- Water Softening without Waste Material

  Adoucissement de l'eau sans rejets

  C. Van der Veen

Discussion

APPLICATION OF STOCHASTIC N.L.P MODEL ON THE OPTIMAL DESIGN OF THE WATER TREATMENT FACILITIES

Kung-Cheh Li. Ph.D.*, Ming-Yang Wu. Ph.D.**

*Director, Bureau of Environmental Protection, Taiwan Provincial Government, Taichung, Taiwan. R.O.C.
**Associate Professor of Habor & River Engineering Department, National Taiwan College of Marine Science & Technology, Keelung, Taiwan, R.O.C.

ABSTRACT

The treatment cost will be increased more rapidly in order to maintain the higher reliability of water quality and quantity. This study is aimed to develop optimal design method to reduce the construction and operating cost of water treatment facilities. This study is also intended to achieve the dual goals of water supply: reliability and economization.

In this work economy of design and reliability of operation is evaluated by the use of mathematical models and Operations Research techniques. And a useful computer program was simulataneously devéloped.

The mathematic model developed by using Nonlinear Programming for the optimal design of the water treatment facilities will be separated into two parts, i.e., Deterministic N.L.P model & Stochastic N.L.P model.

The input water quality is not usually at a constant level, however only Stochastic N.L.P model is considered in this paper.

The main purpose of this paper is aimed to develop a methodology which can assist in decesion-making on how to conduct the changes in the water supply profession and outisde technologies.

KEYWORDS

Two-stage stochastic model; chance-constraint stochastic model; decisin variable; uniform series present worth factor; complementary probability; Hestenes' multiplier method; penalty function; powell's conjugate direction method; quasi-newton methods.

DETERMINISTIC NLP MODEL

A deterministic NLP model is assumed that the input water quality is at a constant level. The characteristics which are considered of interest in constructing a mathematical model for the design and operation of water treatment facilities are: (1) the removal efficiencies of water treatment units, (2) the construction and operating cost of the units, (3) input and output quality conditions, and (4) the operating limitations of each water treatment unit. Once the mathematical model is constructed, and doubt exist about finding the best solution to the model, mathematical programming techniques can be used to find an optimal solution to the model.

The mathematical model can be thought of as consisting of actually two parts. One model is formed by a set of equations and inequalities which limit the choice of the values for the sizes of the units, and is therefore called a structural constraints. The other model evaluates the different combinations of values for the sizes of the units in terms of some measure of effectiveness. It is called the objective function. The objective function for the water treatment model is formed from the construction and operating cost data. The constraints are formed the removal efficiencies of the water treatment units, the input quality conditions, and operating conditions.

The objective in solving the mathematical model constructed in this paper is to determine the sizes of the units so that the overall cost of achieving a desired reduction in impurities is a minimum. The sizes of the units can be called the decision variables of the model, which are expressed in terms of the volume of a unit, the surface area of a unit, or the feed rate of chemical feed to a unit. Removal efficiency is related to the size of the water treatment unit responsible for the change.

The use of past records assumes that the input water quality sequence will repeat in the future or the change of future inputs are known with certainty. This is not true. There is no assurance that the solution will guarantee the desired output quality all the time.

STOCHASTIC NLP MODEL

The input water quality is never constant druing the design life of a water treatment facility. Water treatment units are designed for a level of input quality (design input quality) but there remains a probability that the actual level of input quality will be lower (more impurities) than design conditions. Designers usually assume that this probability is very small. When a worse-than-design input quality occurs, the constraines on output quality (target) could be violated. Therefore, it is desirable to acknowledge the existence of the random input and explicitly establish the reliability of satisfying output water quality targets by a sequence of water treatment units.

Loucks (1981) found that solution of stochastic problems using linear programming results either in a large increase in the number of variables and constraints over the deterministic case to account for alternative possible scenarios or in the use of chance constraints. These two approaches are illustrated as the following description.

Two-Stage Stochastic Linear Programming

Wu (1986) indicated that if there are seven units in the water treatment plant, then, objective function is.

$$\text{Min} \sum_{i=1}^{7} (\text{construction cost}) + E[\sum_{i=1}^{7} C_i D_{iT}] \quad (1)$$

Subject to

$$T \geq (T^1 + T^2 + \ldots + T^7) + (D_{1T} + D_{2T} + D_{3T} + \ldots + D_{7T}) \quad (2)$$

$$T^i_{min} \geq T^i \geq D_{iT} \geq 0 \text{ for all } i$$

Where $E[\Sigma C_i D_{iT}]$ is expected O.M.R cost, C_i is the unit cost which will be added to the units, when units exist the deficit treatment efficiency after input water qualities are known.

And T^i is the impurity removal amount for each treatment unit and each water quality parameter, before the input water qualities are known (for example, turbidity)

T_i is the monthy average input turbidity in a year. T^i's are fixed treatment targets and D_{iT}'s are the amount by which target T^i is not met when the input tarbidity is T. All T^i's and D_{iT}'s are unknow. T is a random variable.

To solve this problem with linear programming, the distribution of T must be approximated by a discrete distribution. Let T take values t_j with probability p_j for j = 1, 2, ... n. The reformulation of the foregoing problem is:

$$\min \sum_{i=1}^{7} (\text{construction cost}) + \Sigma\Sigma p_j C_i D_{ij} \quad (3)$$

Subject to

$$t_j \geq (T^1 + T^2 + \ldots + T^7) + (D_{1j} + D_{2j} + \ldots + D_{7j}) \text{ for all } j \quad (4)$$

$$T^i_{min} \geq T^i > D_{ij} \geq 0 \quad \text{for all } i \text{ and } j \quad (5)$$

For each value of j it is necessary to repeat the basic constraint set which relates the t_j to the target. T^i and deficits D_{ij}. This can cause stochastic linear programs to become quite large. This formulation of the problem is called a Two-STAGE linear program because the targets T_1, T_2 and T_3 are set at the first stage before the input water quality are known, which the deficies D_{ij} are set at the second stage when the water quality is known and the targets are fixed. Additional stages can be added to describe how a problem unfolds over time. However, for more than two or three stages, the linear problem often becomes too big to justify this approach, unless the number of possible combinations in later stages can be restricted.

Chance-constraint Stochastic Linear Programming:

A chance-constraint formulation for the constraints of the model allows the designer to acknowledge the existence of random data and to specify explicitly the percentage of violations of the constraints. The use of chance-constraints will specify the probability of violating each constraint. Since the random component of each constraint is the input water quality, a designer needs only the cumulative frequency distribution of the random input quality to construct a chance-constraint.

Consider the following optimization problem
objective function is

$$\min f(x) \quad (6)$$

subject to

$$gi(x) \leq B_i \quad (7)$$

when only the right-hand side B_i of one or more inequality constraints is random, chance-constraints can be written that define the probability P_i that *the constraint can fail. Thus instead of specifying that*

$$gi(x) \leq E[Bi] \quad (8)$$

for those inequality constraints in which Bi is random, a chance constraint

$$Pr[gi(x) \leq Bi] \leq Pi \quad (9)$$

can be defined, indicating that the constraint can be violated no more than 100 Pi % of the time.

As an example, suppose that 35 mg/l is the minimum alkalinity for produce good floc after pre-chlorination and ALUM feeding. And B_1 is the input total alkalinity, and this quantity is uncertain. It is a random variable, having the cumulative distribution function.

$$F_{B1}(b) = pr\{B_1 \leq b\} \quad (10)$$

where:

$F_{B1}(b)$ = cumulative probability distribution of input total alkalinity

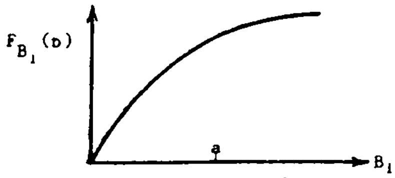

Fig.1 CDF of input total alkalinity in a period

so, $pr\{B_3 \leq 35\} \leq P$ and means (11)

$$pr\{B_1 - \frac{19200}{Q} x_1 - \frac{9840}{Q} x_2 \leq 35\} \leq P \quad (12)$$

The constraints states that the probability of total alkalinity required for coagulation being less than or equal to 35 mg/l is very small. P is a probability that can take values between zero to one, but the values used in this work will always be close to zero because the violation of the constraints must not occur frequently.

eq(12) can be arranged

$$pr\{B_1 \leq 35 + \frac{19200}{Q} x_1 + \frac{9840}{Q} x_2\} \leq P \quad (13)$$

If we say that P is 0.05 (5%). This means that a 5% probability of a input total alkalinity being less than or equal to $(35 + \frac{19200}{Q} x_1 + \frac{9840}{Q} x_2)$ is acceptable.

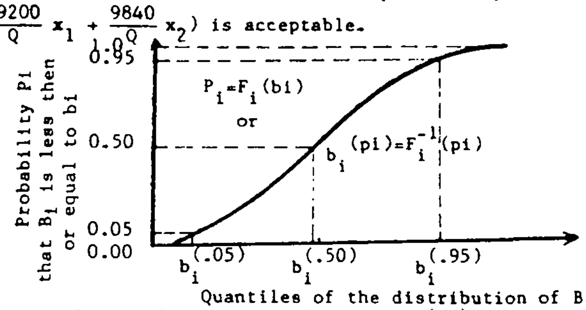

Fig. 2 The cumulative distribution function Fi(bi) relates probabilities Pi with values $bi^{(pi)}$

DEVELOPMENT OF MODEL

Flow chart of the exsisting treatment plant:
Fig.3 is a schematic of the water treatment units.

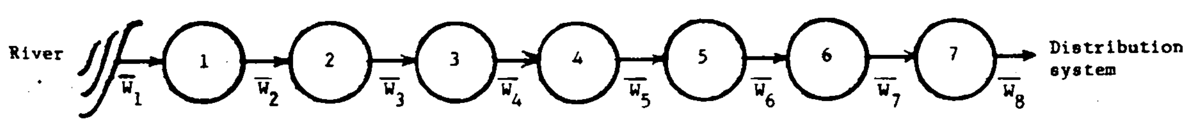

Fig. 3 Flow chart of a treatment plant

where:
- Wj: Vector of water quality parameters into process "j"
- 1: Pre-chlorination
- 2: Alum feeders
- 3: Rapid mixing basin.
- 4: Flocculation basin
- 5: Tube settler sedimentation
- 6: Modified-greenleaf type filter
- 7: Post-chlorination

Decision variable and unit size
- x_1: Feedrate of pre-chlorination (kgs/hr)
- x_2: Feedrate of alum feeder (kgs/hr)
- x_3: Volume of the rapid mixing basin (M^3)
- x_4: Volume of the flocculation basin (M^3)
- x_5: Surface area of the tube settler sedimentation (M^2)
- x_6: Surface area of the modified-greenleaf filter (M^2)
- x_7: Feedrate of post-chlorination (kgs/hr)

Objective function:

The generalized cost function is strictly concave. These cost function are going to be minimized using a heuristic linear programming, However, to develop the cost function for the algorithm, it is necessary to make linear piece-wise approximations of the cost curve. At least three linear approximations are made for each cost curve. A statement of the approximation is shown in figure 4.

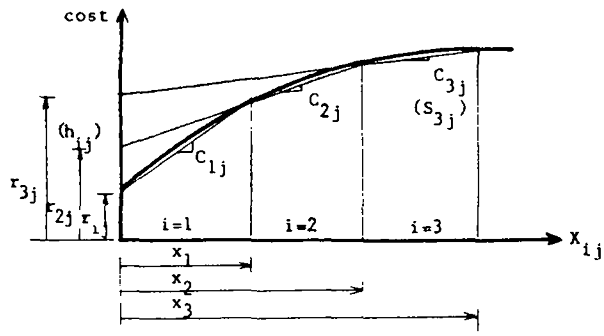

Fig. 4 Piece-wise approximation algorithm

Obj fn:

$$\min \sum_{j=1}^{p} \sum_{i=1}^{3} (z_{ij}r_{ij} + c_{ij}x_{ij}) + \sum_{j\epsilon J} \sum_{i=1}^{3} e_j(o_{ij}h_{ij} + s_{ij}y_{ij}) \tag{14}$$

where:

r_{ij} : fixed cost coefficient, or the ordinate intercept of the i^{th} segment of the construction cost curve for variable x_{ij}.
z_{ij} : integer variable of segment "i" of variable "j".
c_{ij} : cost coefficient, or the slope of the i^{th} segment of the construction cost curve for variable x_{ij}.
x_{ij} : the size of unit "j", or the i^{th} segment of the j^{th} decision variable. (y_{ij} is the same definition)
h_{ij} : fixed cost coefficient, or the ordinate intercept of the i^{th} segment of the operating cost curve for variable y_{ij}.
o_{ij} : integer variable of segment "i" of variable "j".
s_{ij} : cost coefficient, or the slope of the i^{th} segment of the operating cost curve for variable y_{ij}.
e_j : PWF, uniform series present worth factor.

Hillier (1974) indicated that using piece-wise approximation algorithm, the original model will transfer into Mixed Integer Programming problem. The actual objective fuaction for a selected exsisting plant is:

$$\begin{aligned}\min Z = 0.572\ x_1 - 0.00289\ x_1^2 + 0.0422\ x_2 - 0.0000449\ x_2^2 + 0.00386\ x_3 + 0.000136\ x_3^2 \\ + 0.00775\ x_4 - 0.00000052\ x_4^2 + 0.001449\ x_5 - 0.000000063\ x_5^2 + 0.0148\ x_6 \\ - 0.000025\ x_6^2 + 0.844\ x_7 - 0.00406\ x_7^2\end{aligned} \tag{15}$$

Constraints:

The derivation of structual constraints are considered of input water quality, output water quality, treatment efficiency, Retention time, operating limit and treatment characteristics.

1. Deterministic constraints:

Corrosion control relationship:

$$\frac{-32314}{Q}x_1 - \frac{10669}{Q}x_2 - \frac{32314}{Q}x_7 \geq 5.5 - 0.133 \min (A_1) + \max (C_1) \tag{16}$$

where

A_1 : Total alkalinity of input water (mg/l)
C_1 : Free carbon dioxide of input water (mg/l)
min (A_1) : The minimum value of raw water total alkalinity obtained from past records.
min (C_1) : Maximum value of raw water free carbon dioxide obtained from past records.
Q : Design flow rate (CMD)

Alum for congulation

$$\frac{x_2}{0.000430} \geq \log \{\max (T_1)\} + 0.281 \tag{17}$$

where:

T_1 : Turbidity of input water (T.U)

Output turbidity

$$\log 4 \geq 12.4 - 0.047\ x_6 + 0.034 \log T_1 - \frac{0.203}{Q}\ x_3 - \frac{0.952}{Q}\ x_4 - K_T\cdot \frac{2.86}{Q}\ x_5 \tag{18}$$

where

K_T : Removal rate for turbidity in sedimentation basin (1/hr)

Output coliform bacteria

$$0.055\ \frac{84}{Q}\ x_3 + 0.25\ \frac{84}{Q}\ x_4 + K_B\ \frac{3.5}{Q}x_5 - 0.5\ x_6 \geq \log\{\max (B_1)\} - 433.25 \tag{19}$$

where:

B_1 : Coliform bacteria of input water (MPN #/100 ml)

K_B : Removal rate for coliform bacteria in sedimentation basin (1/day)

Total alkalinity for coagulation:

$$\min (A_1) - \frac{19200}{Q}x_1 - \frac{9840}{Q}x_2 \geq 35 \qquad (20)$$

Detention times:

$$\left.\begin{array}{l} x_3 \geq 0.0007Q \\ x_4 \geq 0.021\ Q \\ x_5 \geq 0.012\ Q \end{array}\right] \qquad (21)$$

Hydraulic filter breakthrough:

$$x_6 \geq 0.00563\ Q \qquad (22)$$

Chlorine disinfection:

$$\left.\begin{array}{l} x_1 = Q \cdot D_1 \cdot \frac{10^3}{24} \\ x_7 = Q \cdot D_7 \cdot \frac{10^3}{24} \end{array}\right] \qquad (23)$$

where

D_1 : Design dosage for pre-chlorination
D_7 : Design dosage for post-chlorination

2. Stochastic constraints:

Corossion control relationship

$$-\frac{32314}{Q}x_1 - \frac{10669}{Q}x_2 - \frac{32314}{Q}x_7 \geq 5.5 - 0.133\ F_{A1}^{-1}(\alpha) + F_{C1}^{-1}(1-\alpha) \qquad (24)$$

where

$F_{A1}^{-1}(\alpha) = \max\{A_1 | F_{A1}(a) \leq \alpha\}$, which is the solution for a in the equation $F_{A1}(a) = \alpha$, or the inverse of the marginal cumulative distribution function of imput total alkalinity (mg/l)

$F_{C1}^{-1}(1-\alpha)$ = which is the solution for C in the equation F_{C1} (C) = 1-α.

α : a probability that can take value between zero to one.
1-α : complementary probability of α.

Equation (24) is formally identical to equation (16), its deterministic equivalent, but the random nature of total alkalinity and free carbon dioxide have been used in equation (24).

Alum for coagulation

$$\frac{x_2}{0.00043\ Q} \geq \log\ \{F_{T1}^{-1}\ (1-\alpha)\} + 0.281 \qquad (25)$$

where

F_{T1}^{-1} (1-α) = which is the solution for t in the equation $F_{T1}(t)$ = 1-α.

Output turbidity

$$K_T \frac{84}{Q}x_5 + \frac{28}{Q}x_4 + \frac{5.97}{Q}x_3 + 1.4\ x_6 \geq \log\{F_{T1}^{-1}(1-\alpha)\} + 364 \qquad (26)$$

Output coliform bacteria

$$0.055\ \frac{84}{Q}\ x_3 + 0.25\ \frac{84}{Q}\ x_4 + K_B\ \frac{3.5}{Q} - 0.5\ x_6 \geq \log\{F_{B1}^{-1}(1-\alpha)\} - 433.25 \qquad (27)$$

where

$F_{B1}^{-1}(1-\alpha)$ = which is the solution for b in the equation $F_{B1}(b)$ = 1-α.

Total alkalinity for coagulation

$$-\frac{19200}{Q}\ x_1 - \frac{9840}{Q}\ x_2 \geq 35 - F_{A1}^{-1}(\alpha) \qquad (28)$$

Detention times: which is identical to eq (21).
Hydraulic filter breakthrough : which is identical to eq (22)
Chlorine disinfection

$$\left.\begin{array}{l} x_1 \geq F_{D1}^{-1}(1-\alpha)\ .Q.\ \frac{10^3}{24} \\ x_7 \geq F_{D7}^{-1}(1-\alpha)\ .Q.\ \frac{10^3}{24} \end{array}\right] \qquad (29)$$

STOCHASTIC CONSTRAINTS TRASFERMATION

Cumulative probability density function for water quality:

In the eq(24) to eq(29). We will find that stochastic characteristic has been included in each constraint. And we need to solve the inverse of the manginal cumulative distribution function of input water quality parameters. So the stochastic constraines could be transfered to certainty form. A statement of the relationship between probability and bi(α) is shown in figure 5. And

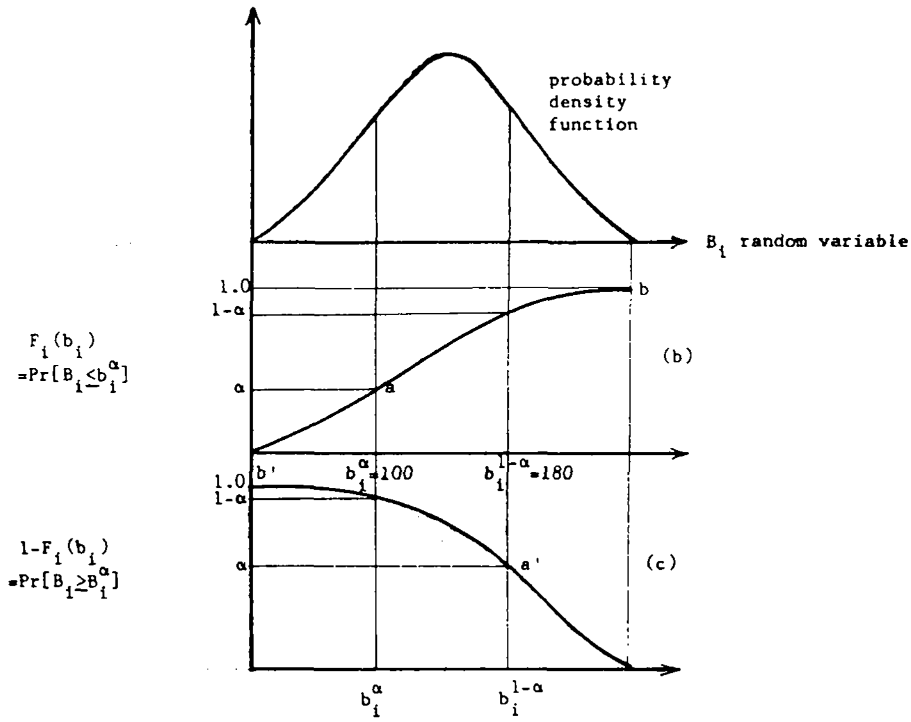

Fig. 5 CDF transformation

In case of $Pr[g_i(x) < B_i] \geq \alpha$, And $\alpha = 0.15$, $b_i^{\alpha} = 100$, $b_i^{1-\alpha} = 180$, if we use diagram (b) to convert it into deterministic equivalent, due to pr[.] > 0.15, then the answer is located on the line interval (ab) and the corresponding b_1^{α} is equal to 100. So the solution is $g_i(x) \geq 100$. But in the original problem we know $g_i(x) \leq B_i$. which must be consistent.

Now we do use diagram (c) to justify the conversion procedure, due to $pr[\cdot] \geq 0.15$, the answer is located on the line(a'b') and the corresponding $b_i^{1-\alpha} = 180$, so the solution is $g_i(x) \leq 180$, which coincides the the original problem $g_i(x) \leq B_i$.

In equation (28)

$$\frac{-19200}{Q}x_1 - \frac{9840}{Q}x_2 \geq 35 - F_{A1}^{-1}(1-\alpha)$$

It is the same as

$$pr\{A3 \leq 35 + \frac{19200}{Q}x_1 + \frac{9840}{Q}x_2\} \leq \alpha \tag{30}$$

Using the foregoing description of conversion algorithm we will obtain

$K = b_i^{1-\alpha}$, K is constant, and K > 0, and

$$K = \begin{cases} b_i^{\alpha} & \text{using diagram (b).} \\ b_i^{1-\alpha} \text{ when} & \text{using diagram (c).} \end{cases}$$

And 1-α = complementary probability of α.

$$A_3 = A_1 - \frac{19200}{Q}x_1 - \frac{9840}{Q}x_2 \geq 35 \tag{31}$$

$$A_1 = K$$

$$K \geq 35 + \frac{19200}{Q}x_1 + \frac{9840}{Q}x_2 \tag{32}$$

Rearrangement we obtain

$$\frac{-19200}{Q}x_1 - \frac{9840}{Q}x_2 \geq 35 - K \tag{33}$$

Deterministic equivalent for the stochastic model.
Objective function
Since the objective function excluded the probability item, it need not convert.
Constraints
<u>Total alkalinity for coagulation.</u>

$$\frac{-19200}{Q}x_1 - \frac{9840}{Q}x_2 \geq 35 - F_{A1}^{-1}(\alpha) \qquad (28)$$

that is:

$$F_{A1}(35 + \frac{19200}{Q}x_1 + \frac{9840}{Q}x_2) \leq \alpha \qquad (34)$$

or:

$$pr\{A_1 \leq 35 + \frac{19200}{Q}x_1 + \frac{9840}{Q}x_2\} \leq \alpha \qquad (35)$$

Using diagram (b) in Fig.5 and Fig.6 — CDF of the total alkalinity. If the deceision maker let $\alpha = 0.25$, or $1-\alpha = 75\%$, $Q = 75000^{CMD}$ we can obtain easily that

$$35 + \frac{19200}{75000}x_1 + \frac{9840}{75000}x_2 \leq 48.5 \qquad (36)$$

or

$$0.128\ x_1 + 0.066\ x_2 \leq 13.5 \qquad (37)$$

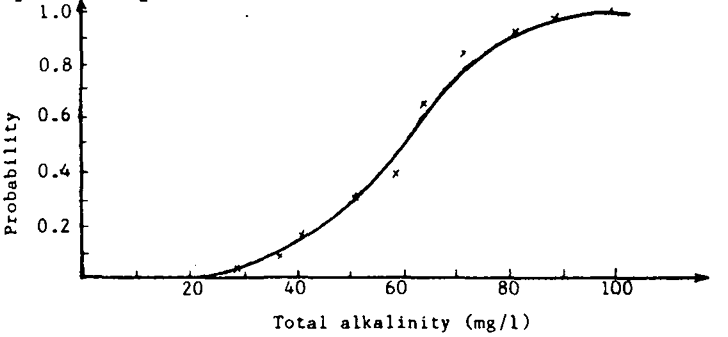

Fig. 6 CDF of total alkalinity

Corrosion control relationship:

when $\alpha < 0.6$, it will

$$0.215\ x_1 + 0.071\ x_2 + 0.215\ x_7 \leq -0.54 \text{ (consistent)} \qquad (38)$$

we enlarge $\alpha = 1.0$, Now

$$0.215\ x_1 + 0.271\ x_2 + 0.215\ x_7 \leq 4.14 \text{ (inconsistent but unreasonable)} \qquad (39)$$

The output water quality of the selected existing plant must be corrosive anyway. If we do not neglect this constraint in our structual constraints then, we can't obtain the feasible solution in our model. The sensivility analysis is necessary for conclusion.

Alum for coagulation

when $\alpha = 0.25$

then $x_2 > 109.4$ (40)

Output turbidity

$\alpha = 0.25$

then $0.213\ x_3 + x_4 + 0.126\ x_5 + 7500\ x_6 \geq 1847491$ (41)

Output coliform bacteria

$\alpha = 0.25$

then $-x_3 - 4.55\ x_4 - 0.057\ x_5 + 16200\ x_6 \leq 13982985$ (42)

USING MULTIPLIERS METHOD TO SOLVE THE NONLINEAR PROGRAMMING PROBLEM

Hestenes' method of multiplier

The basic concept of the usual solution method of Nonlinear Programming is to apply some iterative formula within the feasible region to approach the optimal solution. Whenever it leaves the feasible region, it must be pulled back into the feasible region.

For problems with equality constraines, there will be a lot of pull-in operations. In this research a concept of flexible tolerance is proposed. Kao (1985) found that a tolerance is allowed for each constraint. In the process of calculations, the tolerance is reduced gradually so it approaches zero when the optimal solution is reached.

In this way many pull-in operations will not be necessary any more so intuitively this is a feasible idea. Hestenes' method of multipiers is the major concept in this research.

A flow-chart of hestene's multiplier method is shown in figure 7

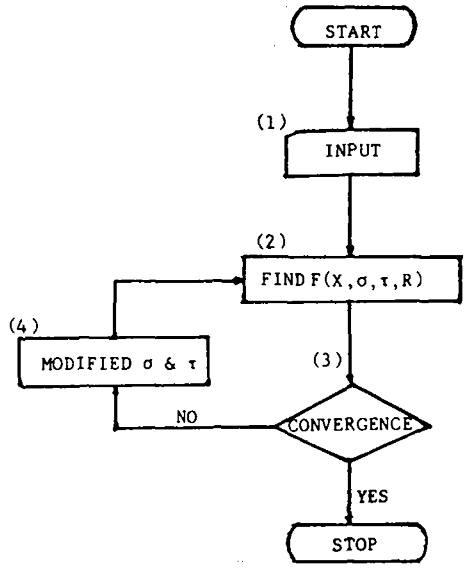

Fig. 7 Flow CHART for multiplier

COMPUTER PROGRAM FOR MULTIPLIER METHOD

Using Chiang Kao's computer program.

In order to satisfy our model, here we had modified the original program, especially in some subroutines and main program. Applendix is the feasible program.

Input data:

There are two types in the computer program for data input.
Using READ format, we input N1(numbers of variable), NEQ (numbers of equality constraints), NGE (numbers of in equality constraints), R (penalty function), x^o (the coordinate of initial point).

In subroutine FUN we READ objective function, in Subroutine CON we READ structural constraints.

The penalty constant — R value, we use 1, 10, 10^2, 10^{-1}, 10^{-2} ... etc. intuitively.

The initial value of σ_o and τ_o are seted to zero.

Finding solution:

Function F has not constraints, in this work we use powell's conjugate direction method to find solution. Powell's method will be very efficient when the N-value is smaller, but when the N-value enlarge, no efficiency this method must be. So maybe we can use DFP or BFGS — one of the Quasi-Newton Methods in the future research.

Results.

Tab.1 is the solution for a selected existing plant. Using of Multiplier Method.

Table 1. Solution for a case study

Objective function	$\min z = 0.572x_1-0.00289x_1^2+0.0422x_2-0.0000449x_2^2+0.00386x_3+0.000136x_3^2+0.00775x_4-0.00000052x_4^2+0.001449x_5-0.000000063x_5^2+0.0148x_6-0.000025x_6^2+0.844x_7-0.00406x_7^2$									
Design period	Random consideration	Objective Value (NT$$10^6$)	The optimal solution of decesion variables							α-value
			x_1	x_2	x_3	x_4	x_5	x_6	x_7	
25 yrs	Deterministic	57.69866	31.25	181.4	104	3125	1800	844.5	5	
	Stochastic	55.60036	31.25	109.4	104	3925	1800	844.5	5	α=0.25

CONCLUSION

The objectives of this work were to evaluate existing water treatment plant design criteria and operation by developing a mathematic model for the design and operating of water treatment facilities. Once the model was developed, optimization techniques were used to search and find optimal solution to the model.

It is felt that this work helps to explain the reliability that water treatment facilities have to provide good quality and quantities of drinking water.

The removal efficiencies used in this work were estimated from existing data and were quantified by means of removal efficiency equations. These equations are pessimistic in the sense that the expected removals will be greater than those specified by the equations.

Due to the limit space, the derivation of structural constraints and description of new type facilities are neglected.

The probability of violating a constraint, denoted by α, is related to the input water quality. For this work it is obtained that this probability should be at the most equal to 0.25 if no modified designs are used. We'll find easily that the output water quality has only 75% of operating reliability even if we neglect the corrosion.

If we modify the flow chart by means of adding the lime feeder between the Alum-feeder and Rapid mixing basin then the α-value becomes to 0.01 that means the operating reliability increasing to 99.9%.

On an DCD-CYBER 170 the average execution time was 0.036 seconds. The speed of computer runs allowed the performance of many experiments. The age of 32-bits personal computer is coming. It will be convinient to solve the mathematic model.

Surface water supplies were the only ones considered as the raw water source in this work. Ground water could be included in a similar analysis using softening and aeration type units. Deep bed filter was not included too.

The quantity and thusly the cost of chlorine used for pre-chlorination is greater than post-chlorinatin but pre-chlorinatin does reduce bacteria loads on filter, which may bring about a reduction in the filtration surface area.

Due to the pre-chlorination process and it's greater dosage. There exists a New problems i.e; THM & its precursors, thus the treatment process or technique must be considered in the future research. There are oxidation, aeration, adsorption, Resin, clarification, source control and changing the point of chlorination.

Another important aspect of water treatment plant design should be flexibility to respond to new information of all kinds.

ACKNOWLEDGEMENT

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APPENDIX COMPUTER PROGRAM FOR MULTIPLIER METHOD

```
      PROGRAM MOM(INPUT,OUTPUT)
      DIMENSION X(50),Y(50),EQ(50),GE(50),TAU(50),SIGAMA(50)
      COMMON,N,NEQ,NGE,R,TAU,SIGMA
      READ *,N,NEQ,NGE,R,IPRINT
      READ *,(X(I),I=1,N)
      TTOL= 1.E-5
      LIMIT=100
      PRINT 10,N,NEQ,NGE,R
   10 FORMAT("IN=",I3,",
     *  NEQ=",I3,",    NGE=",I3,",     R=",F8.2)
      CALL SECOND(T1)
      CALL FUN(X,FX)
      CALL CON(X,EQ,GE)
      TOL=0.
      IF(NGQ.EQ.0) GO TO 20
      DO 15 I=1,NEQ
      TAU(I)=0.
   15 TOL=TOL+EQ(I)**2
   20 IF(NGE.EQ.0) GO TO 30
      DO 25 I=1,NGE
      SIGAMA(I)=0.
   25 IF(GE(I).LT.O) TOL=TOL+GE(I)**2
   30 TOL=SQRT(TOL/NEQ+NGE))
```

```
   35 IF(ITER.EQ.O.OR.IPRINT.EQ.1) CALL XPRINT(N,ITER,
     *FX,TOL,X)
      DO 40 I=1,N
   40 Y(I)=X(I)
      FY=FX
      ITER=ITER+1
      IF(ITER.LT.LIMIT) GO TO 45
      PRINT *,'*****REACHING THE LIMITED ITERATIONS*****'
      GO TO 80
   45 CALL POWELL(X,DUMMY)
      CALL FUN(X,FX)
******TEST FPR CPMVERGEMCE
      CALL CON(X,EQ,GE)
      TOL=O.
      IF(NEQ.EQ.O) GO TO 60
      DO 50 I=1,NEQ
      TOL=TOL+EQ(I)**2
   50 TAU(I)=TAU(I)+EQ(I)
   60 IF(NGE.EQ.O) GO TO 75
      DO 70 I=1,NGE
      IF(GE(I).LT.O) TOL=TOL+GE(I)**2
      SIGAMA(I)=SIGAMA(I)+GE(I)**2
   70 IF(SIGAMA(I).GT.O.) SIGAMA(I)=O.
   75 TOL-SQRT(TOL/(NEQ+NGE))
      IF(TOL.GT.TTOL.OR.CONVRG(FY,FX,Y,X,N).LT.O.) GO TO
     *35
   80 CALL XPRINT(N,ITER,FX,TOL,X)
      CALL SECOND(T2)
      TIME=T2-T1
      PRINT 90,TIME
   90 FORMAT(///"    THE EXECUTION TIME IS",F10.4,"
     *SECONDS")
      STOP
      END
      FUNCTION PENAL(X)
      DIMENSION X(50),EQ(50),GE(50),TAU(50),SIGAMA(50)
      COMMON N,NEQ,NGE,R,TAU,SIGAMA
      CALL FUN(X,FX)
      CALL CON(X,EQ,GE)
      PENAL=O.
      IF(NEQ.EQ.O) GO TO 20
      DO 10 I=1,NEQ
   10 PENAL=PENAL+(EQ(I)+TAU(I))**2-TAU(I)**2
   20 IF(NGE.EQ.O) GO TO 40
      DO 30 I=1,NGE
      TMP= GE(I)+SIGAMA(I)
      IF(TMP.GT.O.) TMP=O.
   30 PENAL=PENAL+TMP**2-SIGAMA(I)**2
   40 PENAL=FX+R*PENAL
      RETURN
      END

      SUBROUTIRE POWELL(X,FX)
      DIMENSION X(50),Y(50),S(50),BEFORE(50),DIRECT(50,50)
      DIMENSION TAU(50,SIGAMA(50),EQ(50),GE(50)
      COMMON N,NEQ,NGE,R,TAU,SIGAMA
      LIMIT=200
      N=N-1
      STEP=1.
      STEPA=STEP
      ITER=0
      FX=PENAL(X)
   26 DO 28 I=1,N
      DO 27 J=1,N
   27 DIRECT(J,I)=0.
   28 DIRECT(I,J)=1.
      STEP=STEPA
   30 ITER=ITER+1
      IF(ITER.GT.LIMIT) GO TO 90
      F1=FX
      DO 40 I=1,N
   40 BEFORE(I)=X(I)
      SUM=O.
******FIND THE MAXIMUM CHANGE IN EACH SEARCH DIRECTION.
      DO 60 I=1,N
      DO 45 J=1,N
   45 S(J)=DIRECT(J,I)*STEP
   48 CALL SEARCH(X,Y,S,FX,FY,N)
      IF(FX-FY.LE.SUM) GO TO 50
      ISAVE=I
      SUM=FX-FY
```

```
   50 DO 55 J=1,N
   55 X(J)=Y(J)
   60 FX=FY
      F2=FX
      DO 65 I=1,N
   65 Y(I)=2.0*X(I)-BEFORE(I)
      F3=PENAL(Y)
      IF(F3.GE.F1.OR.(F1-2.*F2+F3)*(F1-F2-SUM)**2.GE.
     *0.5*SUM*(F1-F2)**2 GO TO 80
******A NEW SEARCH DIRECTION IS REQUIRED. FIRST REMOVE
     *ROW ISAVE.
      IF(ISAVE.GE.N) GO TO 70
      DO 68 I=ISAVE,N1
      II=I+1
      DO 68 J=1,N
   68 DIRECT(J,I)=DIRECT(J,II)
   70 A=0.
      DO 72 J=1,N
      DIRECT(J,N)=X(J)-BEFORE(J)
   72 A=DIRECT(J,N)**2+A
      A=SQRT(A)
      DO 75 J=1,N
      DIRECT(J,N)=DIRECT(J,N)/A
   75 S(J)=DIRECT(J,N)*STEP
      CALL SEARCH(X,Y,S,FX,FY,N)
      FX=FY
      DO 79 I=1,N
   79 X(I)=Y(I)
      GO TO 85
******TEST FOR CONVERGENCE.
   80 IF(F2.LT.F3) GO TO 85
      DO 82 J=1,N
   82 X(J)=Y(J)
      FX=F3
   85 IF(CONVRG(F1,FX,BEFORE,X,N).GT.O.) RETURN
      IF(FX.GE.F1) GO TO 26
      IF(F1-FX.GE.O) STEP=0.4*SQRT(F1-FX)
      IF(STEPA.LT.STEP) STEP=STEPA
      GO TO 30
   90 PRINT *,'******FAILED IN POWELL SEARCH*****'
      STOP
      END

      SUBROUTINE SEARCH(X,Y,S,FX,FY,N)
*DSC-POWELL (COGGIN) METHOD OF LINE SEARCH
*SEARCH ALONG DIRECTION S FORM POINT X TO FIND THE
     *MINIMUM POINT Y
      DIMENSIONX(50),Y(50),S(50)
      LIMIT=200
      TOL1=0.001
      TOL2=TOL1/100.
      XTOL=FTOL=0.00001
      FA=FB=FC=FX
      DA=DB=DC=C=O.
      ITER=O.
      D=1.
******BRACKET SEARCH
   20 DO 22 I=1,N
   22 Y(I)=X(I)+D*S(I)
      IF(ITER.GT.LIMIT) RETURN
      ITER=ITER+1
      FY=PENAL(Y)
      IF(FY-FA) 25,30,40
   25 FC=FB=FB=FA=FA=FY
      DC=DB=DB=DA=DA=D
      D=2.*D
      GO TO 20
   30 IF(ITER.GE.2) GO TO 45
      D=0.5*D
      DO 32 I=1,N
   32 Y(I)=X(I)+D*S(I)
      FB=PENAL(Y)
      IF(FB.LT.FA) GO TO 38
******FUNSION VALUE INDEPENDENT OF THIS DIRECTION
      DO 35 I=1,N
   35 Y(I)=X(I)
      FY=FX
      GO TO 80
   38 DB=D
      DA=2.*D
      FA=FY=FY=FB
```

```
      GO TO 50
   40 IF(ITER.GE.2) GO TO 45
      FB=FY
      DB=D=D=-D
      GO TO 20
   45 FC=FB=FB=FA=FA=FY
      DC=DB=DB=DA=DA=D
      IF(D.GE.O.) GO TO 50
******CHANGE THE RELATION FROM A-B-C TO C-B-A
      TMP=DC=DC=DA=DA=TMP
      TMP=FC=FC=FA=FA=TMP
******QUADRATIC INTERPOLATION
   50 ITER=ITER+1
      IF(ITER.GE.LIMIT) RETURN
      A=FA*(DB-DC)+FB*(DC-DA)+FC*(DA-DB)
      D=0.58(DA+DB)
      IF(A.NE.O.) D=0.5*(FA*(DB*DB-DC*DC)+FB*(DC*DC-DA
     **DA)+
     *FC*(DA*DA-DB*DB))/A
******IF D IS OUT OF THE RANGE OF C-B-A, THEN RETURN
     *THE CURRENT POINT
      IF(D.GT.DC.AND.D.LT.DA) GO TO 58
      IF(FY.LE.FX) GO TO 80
      DO 56 I=1,N
   56 Y(I)=X(I)
      FY=FX
      GO TO 80
   58 DO 60 I=1,N
   60 Y(I)=X(I)+D*S(I)
      FY=PENAL(Y)
******TERMINATIN CHECK
      A=1.
      IF(ABS(FB).GT.TOL2) A=1./FB
      A=ABS((FB-FY)*A)
      IF(A.GT.TOL1) GO TO 63
      IF(N.NE.1) GO TO 61
      IF(A.GT.FTOL) GO TO 63
      A=1.
      IF(ABS(D).GT.XTOL) A=1./D
      IF(ABS((D-DB)*A).GT.XTOL) GO TO 63
   61 IF(FY.LT.FX) GO TO 80
      TOL1=TOL1/10.
      IF(TOL1.GT.1.E-8) GO TO 63
      DO 62 I=1,N
   62 Y(I)=X(I)
      FY=FX
      GO TO 80
   63 IF(D.GT.DB) GO TO 70
C C-D-B-A
      IF(FY.GT.FB) GO TO 65
      FA=FB=FB=FY
      DA=DB=DB=D
      GO TO 50
   65 FC=FY
      DC=D
      GO TO 50
C C-B-D-A
   70 IF(FY.GT.FB) GO TO 75
      FC=FB=FB=FY
      DC=DB=DB=D
      GO TO 50
   75 FA=FY
      DA=D
      GO TO 50
   80 RETURN
      END

      FUNCTIN CONVRG(FX,FY,X,Y,N)
******TEST FOR CONVERGENCE
      DIMENSION X(50),Y(50)
      EPSLN=0.0001
      DPSCON=0.00001
      CONVRG=-1.
      IF(ABS(FY)-EPSLN) 20,20,10
   10 IF(ABS((FY-FX)/FY)-EPSLN) 30,30,70
   20 IF(ABS(FY-FX)-EPSLN) 30,30,70
   30 DO 60 I=1,N
      IF(ABS(Y(I))-EPSLN) 50,50,40
   40 IF(ABS((Y(I)-X(I))/Y(I))-EPSLN) 60,60,70
   50 IF(ABS(Y(I)-X(I))-EPSLN) 60,60,70
   60 CONTINUE
```

```
      CONVRG=1.
   70 RETURN
      END
      SUBROUTINE XPRINT(N,ITER,FX,TOL,X)
******OUTPUT INFORMATION
      DIMENSION X(50)
      PRINT 20,ITER,FX,TOL
      DO 10 I=1,N
   10 PRINT 40,I,X(I)
   20 FORMAT(///' ITERATON',I5,5X,'F=',E15.8,5X,'TOLERANCE=',E15.8)
   40 FORMAT(5X,'X(',I2,')=',E15.8)
      RETURN
      END

      SUBROUTINE FUN(X,FX)
      DIMENSIN X(50)
      FX=5.332*X(1)-0.0234*X(1)**2+0.214*X(2)-0.00015*X(2)**2
     *-0.109*X(3)+0.0017*X(3)**2+0.22*X(4)-0.00000014*X(4)**2
     *+0.0019*X(5)-0.000000035*X(5)**2+0.0505*X(6)-0.000005*X
     *(6)**2
     *+8.275*X(7)-0.036*X(7)**2+0.214*X(8)-0.00015*X(8)**2
      RETURN
      END

      SUBROUTINE CON(X,EQ,GE)
      DIMENSION X(50),EQ(50),GE(50)
      GE(1)=-0.128*X(1)-0.066*X(2)+0.2864*X(8)-8
      GE(2)=-0.215*X(1)-0.071*X(2)-0.215*X(7)+0.289*X(8)-6.309
      GE(3)=0.213*X(3)+X(4)+0.216*X(5)+7500*X(6)-1853888
      GE(4)=X(3)+4.55*X(4)+0.057*X(5)-16200*X(6)+13969369
      GE(5)=X(1)-31.25
      GE(6)=X(2)-172.8
      GE(7)=X(3)-104.
      GE(8)=X(4)-3125.
      GE(9)=X(5)-1800.
      GE(10)=X(6)-844.5
      GE(11)=X(7)-5.
      RETURN
      END
```

MEMBRANE AND BIOTECHNOLOGY : THE 90's METHODS OF PRODUCING WATER

Jentoft Olsen,
Manager, Research and Development
De Danske Sukkerfabrikken - DDS RO
P.O. Box 149, DK-4900 Naskov, Denmark

ABSTRACT

Membrane separation will lead to significant progresses in water treatment for both drinking water and waste water applications. Membrane separation represents also a key to the development of biotechnology and advanced bioreactors. Many problems still need to be resolved : the fouling of the membranes is the major one and the cost of the membrane system is another important one. In order to overcome these, ambitions collaborative research programs, BRITE and EUREKA, are being conducted at the European level. With them, membrane technology will be commonly available by the turn of the century.

KEYWORDS

Membranes, biotechnology, filtration, water treatment.

INTRODUCTION

The supply of water of high purity is, in undustrialized countries, a problem of growing importance. The quality criteria for drinking water will be considerably reinforced and the demand by the industry for process water with very specific and very pure composition, will keep rapidly increasing. Simultaneously the regulations for the discharge of waste waters in the environment will become more stringent and the technologies for biological wastewater treatment will have to become more and more reliable. Membrane filtration in this prospect may bring precious solutions, not only as an original and efficient physico-chemical method of separation but also as an essential component of high rate bioreactors.

WHAT ARE THE MEMBRANES ?

Membranes are thin films of synthetic organic or inorganic (ceramics) materials, which can bring about a very selective separation between a fluid and its components. The fluid may be a gaz or a liquid and in our case, water.

Membranes can be casted in various shapes : flat sheets (the most common), tubes of various sizes (the smaller ones being called "capillary") and hollow fibers with an outside diameter below a tenth of a millimeter. Generally speaking, the ceramics membranes are more resistant to pressure and chemicals -particularly to disinfectants such as chlorine-, but more cumbersome and expensive. Organic membranes on the other hand, are more flexible and can be put into compact modules with very high surface area. As an example a module with an overall volume of one cubic meter can hold a flat sheet membrane spirally wound with a surface area of 1,000 square meter and this surface area would be almost doubled with hollow fibers.

Membranes are classified according to the size of the particles which they separate. Figure 1, indicates the different methods of separation which are used and shows the position of the main membrane treatment categories. Reverse Osmosis (RO) separates ions, through diffusivity, and UltraFiltration (UF) and MicroFiltration (MF) separate molecules and particles. The surface of UF and MF membranes is thus covered with pores which bring about the specific separation. They are usually in the range of 10^{-7} millimeter (0.1 micrometer). The UF membranes have smaller pores than the MF ones. These pores can be clogged and a very large portion of the research efforts is aimed at preventing or retarding this fouling. UF membranes will produce less filtrate (or permeate) but will also foul less than the MF membranes. The distinction between UF an dMF membranes however is difficult and this paper, which focuses on these particular types of membranes will confound them. Typically UF and MF membranes operate at low pressures, around 1 bar.

Membranes are assembled in a case, called module which includes several square meters of them. Figure 2 is a schematic of a module with capillary tubes. the manufacturing problems of the modules include, in particular, the arrangement of the membrane within the shell and the sealings at both ends.

HOW MEMBRANES WORK ?

Most UF and MF membranes are operated "cross-flow". Figure 3 represents this mode of operation, where water is flown at high velocity tangentially to the membrane. The particles are carried away by the water flow and the cake thickness is kept to a minimum. The hydrodynamics of the system are thus of determining importance.

Particles, however will eventually attach to the membrane surface either mechanically or more likely through physical-chemical forces. The interactions between the membrane and the particles should therefore be repulsive due to the membrane composition and/or the water particles conditionning (pretreatment).

Figure 4 schematically represents the production of a UF membrane operated cross-flow. The flux of filtrate or permeate is typically expressed in liters per hour per square meter of membrane per bar of pressure ($l/h \times m^2 \times b$). Without backflushing, because of the cake built-up it would constantly decrease. Backflushing, however, resumes the level of the flux to almost original value. The remaining difference indicates the formation of an irreversible fouling which will need, in order to be removed, a more thorough cleaning. Figure 4 also indicates that membranes are frequently backflushed for a very short period of time, typically every 15 minutes for a few seconds, but after several days, they need additional chemical cleaning. Eventually the membranes will have to be replaced. Altogether the flux of permeate is small as compared to the overall water flow and even if UF and MF membranes are operated at relatively low pressure, their operational cost -i.e. pumping energy- still remains at an appreciable level. The duration of the membrane in time and for a specific water application, is still unknown. It is expected to be in the order of several years. The longer the better ! These points, of course, are important factors for the economics of the process and are under detailed investigation.

In an industrial process, modules are connected in series and parallel. These arrangements can be operated without any problem when one module is being flushed, cleaned or replaced. They also keep the overall water loss below a few percent.

EXISTING AND POTENTIAL MEMBRANES APPLICATIONS

Today the only large scale application of membrane to water treatment is desalination by RO and UF/MF are still unknown. Their main use is in the food industry for milk processing or in medical applications such as kidney dialysis. In the biotechnological industries, in down-stream processing, UF and MF are also used to separate a wanted component (product) from an unwanted one e.g. cells, cell debris. Also the combination of fermenter and membrane filtration systems is coming up. By this process it is possible to establish a continuous extraction of active substance from the broth and at the same time return the microorganisms to the fermenter, maintaining a high concentration of biomass.

Public water treatment, however, represents the most important potential market for UF and MF, provided that the throughput is sufficiently high and the cost sufficiently low. Once available these membranes will be used in turn for other applications outside of the water field. Water treatment, in other words, will pull membrane filtration technology for the coming few years.

WHAT ADVANTAGES MEMBRANES WOULD BRING ?

Clarification

UF and MF membranes can remove the suspended solids and the large molecules. they can also separate the microorganisms including viruses, provided that their cut-off is sufficiently low. In conventional water treatment they can theoretically replace sand filters and clarifiers. This is represented in Figure 5. In most cases no chemicals would be required for coagulation nor disinfection, except of course for a safety disinfection on the treated water before its supply through the network. For the waters with a more complex composition, chemicals might be needed but at dosages considerably lower than those usually applied in existing clarification plants. This abandonment of chemicals and the ability to remove the germs, represent a clear advantage of membrane filtration. A better quality water will, indeed be produced. Another advantage of using membranes is that they would result in much smaller plants -at least 50 % smaller- than the conventional ones. The future is to more compact plants and membranes bring here another clear advantage.

Additionnal attractive features of membranes are that they are reliable -no break through can occur-, they are easy to operate and the plant can be made fully automatic and at last, plant design will be considerably simpler. In many ways membrane filtration represents a dream for water treater people !

Bioreactors

UF and MF membranes will also bring clear advantages to biological treatments for both drinking water (e.g. nitrification) and waste water treatment. They will lead to high performance bioreactors similar to those already in use in the food and drugs area. In fact, this application of membrane "biotechnology" to water had been thought of years before clarification.

The Aquarenaissance Project

In Japan the Ministry of International Trade and Industry (MITI) started an ambitions Research and Development program in late 1985, called Aquarenaissance 90. Its objective is to develop by 1990, compact high performance waste water treatment plants with fully integrated membrane bioreactors. The surface area of the plants should be divided by 4, as compared to conventional plants, the cost both capital and operational should be divided by 2, the residual pollution in the treated water should be divided by 2.5 and most important, the sludge production should be divided by at least 4.

The program is schematically designed into four steps, summarized in Figure 6. It goes from existing conventional activated sludge basins combined with primary and secondary clarifiers to, step 4, bioreactors where the biomass would be confined between two UF/MF membranes. The membranes would thus replace the clarifiers and allow by protecting the biomass, the use of more concentrated and more selective bacterial strains. UF and MF membranes would thus open the door to real applications of biotechnology, such as the use of genetically engineered bacteria, in water treatment. It should be noted that step 2 (Figure 6) where membrane separation replaces the secondary clarifier, is already commonly applied in recycling "building" plants in Japan.

THE PROBLEMS YET TO BE SOLVED

How to Control the Fouling ?

In order to control the fouling, thorough investigations of the mechanism of interactions between particles and membranes have to be made. The first step is a detailed analysis of the foulants ; First results, such as those reported in figure 7, indicate that foulants are specific organic compounds (polysaccharides in this case) which do not necessarly reflect the bulk organic composition. Sophisticated trace analytical methods are thus being developed : GC-MS-Pyrolysis is one of them together with observation methods such as electron microscopy, ion emission spectroscopy, infrared spectroscopy with Fourier transform, etc.

The control of fouling will be acheived in most cases by adjusting the membrane surface properties in order to repel particles. In waters with complex or variable composition, such as surface waters the particles characteristics will have to be equally adjusted.

A fine pretreatment will be required. Figure 8 summarizes the possible strategies for this pretreatment. Strategy 1 would not be feasible for drinking water production. Strategy 2 is the most likely to be used : particles would be destabilized by small coagulant dosages, mild oxidation or carbonate precipitation. The cake thickness on the other hand may rapidly build up and may result in appreciable reduction of the permeate flux. In this case the hydrodynamics of the system will have a determining effect. Strategy 3 is theoretically the best, but the chemical dosage and the membrane surface characteristics will have to be very finely tuned.

How to Manage the Fouling ?

Whatever adjustments will be made in terms of membranes-particles interactions, the fouling will eventually occur and the question is how to manage it ? The design of the module, the arrangement of the different modules and the cleaning technique will all be of significant importance. The key to success in membrane filtration will be the ability to adjust all these parameters to water characteristics and a comprehensive understanding of water seems absolutely necessary.

How to Reduce the Cost ?

In order to match the conventional treatment costs, drastic improvements should be made not only in the performance of membranes but also in their manufacturing. Stabilized, average flux should be at least in the range of 200 l/h per m^2 of membrane and cost of membrane and module should be below 30 US dollars per m^2 of membrane. In comparison with the existing performance this would mean at least doubling the flux and halving the cost ! This would thus result with a carefully engineered module environment in a plant 15 to 25 % less expensive than a conventional one. From the operational standpoint the service pressure should be kept as low as possible and if membrane last long enough with scarce chemical cleaning the overall runing cost would be 5 to 15 % lower than conventional clarification. This of course with a treated water of better quality.

THE EUROPEAN RESEARCH AND DEVELOPMENT EFFORTS

The task to be accomplished is thus to develop a completely new membrane filtration system including new membranes made of stable, approved and inexpensive materials suitable for mass production and at the same time develop a biotechnological waste water process where the membrane filtration system is an integrated part.

Such a project is bound to become very large, involving a great many disciplines and areas to be clarified before a complete and finished concept can be reached. In view of this DDS from Denmark and Lyonnaise des Eaux from France have entered into a close co-operation based on an EUREKA-supported project. Lyonnaise des Eaux, the mother-firm of Degrémont, are known world-wide as experts in all aspects of water treatment ranging from waste water to distribution of high quality drinking water. Lyonnaise des Eaux have at their disposal advanced testing and research facilities including one of the most advanced analytical laboratories in Europe for water quality control and research.

DDS are among the pioneers in the world within membrane filtration and today range among the leading companies supplying production plants to the food industries as well as the biotechnological industries. The Company's membrane filtration facilities include everything from membrane research and production to engineering, production, and erection of complete plants and processes.

The membrane production facilities manufacture the whole range of membranes from the most simple cellulose acetate membrane to thin-film composite desalinaton membranes and surface coated UF/MF membranes.

In its initial phase the cooperation is based on the know-how obtained by the parties from a common BRITE project (Basic Research in Industrial Technology for Europe), an EEC supported basic research program within membrane technology, on fouling of membranes and hydrodynamics, which started about 2 years ago. EUREKA is the second research program. It is organized in 6 phases :

1. Basic research on membranes and modules,
2. Construction of prototypes and testing on known products,
3. Process development for water treatment based on developed prototypes,
4. Development and optimization of production facilities for membranes and modules,
5. Establishing of production facilities,
6. Establishing demonstration plants for different membrane end-use processes.

Two different types of membrane/modules will be developed and tested. DDS will develop a module based on the flat membrane concept, whereas Lyonnaise des Eaux will develop modules on the basis of the hollow-fiber concept.

The results from the fluid dynamic studies from BRITE will be adapted to these new systems to minimize energy consumption as this is a must when treating low-cost products like water. Commercial UF/MF plants of today have an energy consumption 3-4 times higher than that.

The most serious problem with membrane filtration today is the fouling of membranes, in the form of a physical blocking of the surface. This can be solved in various ways, either by increased sheer on the surface of the membrane by vigorous pumping at the expense of an increased energy demand, or increased cleaning activity with strong detergents -expensive and time- consuming.

The BRITE research work has already shown that a certain surface treatment of the membranes can increase their resistance to fouling with a dramatic effect on the capacity. On some difficult food products the capacity increased more than 10-fold by this surface.

The membranes must be very resistant to the environment in which they are going to operate, their lifetime should be at least 4-5 years by continuous operation.

The physical framework in which the membranes are to be incorporated must designed in such a way that they can be mass produced, must be inexpensive, easy to clean and easy to change and, last but not least, must ensure a completely leakfree barrier between the feed (waste water) and the product (drinking water).

Prototypes of membrane filtration plants based on this new product will be constructed and tested on known products. In this way they can be compared with existing systems of today and operating parameters can be evaluated.

Process development for water treatment based on these new systems vill be started by a study on the use of ultrafiltration for the production of ultrapure water. This task includes evaluation of the ultrafilters to tackles the problems brought about by organic leakage from plastic ducts.

The fixed culture denitrification process presently used in drinking water treatment will be compared with and possibly replaced by a free-culture membrane filtration process. This should improve the efficiency of this process and especially increase its ability to handle ammonia peak concentrations.

The replacement of deep-bed filtration systems for treatment of surface water, by UF or MF, will be investigated, as well as water treatment prior to reverse osmosis desalination. This latest item is believed to be a major issue for off-shore water treatment equipment, as membrane pretreatment is expected to yield more compact and lighter units, hopefully without any chemical treatment.

A totally new drinking water treatment plant mainly relying on membrane separation for both particle and organic removal will be studied. The result of the above task will be used for this major topic. Additionally, sludge thickening and conditioning will be investigated, using chemical treatment and specially designed filtration modules. such a plant is expected to need much less chemicals, if any, than conventional drinking water treatment plants.

In the waste water treatment process the replacement of conventional filters, settlers etc., by membrane filters downstream of biological reactors will be studied, with the purpose of collecting information and know-how for the development of a totally new membrane bioreactor. An essential part of this study is to investigate the influence of high biomass concentrations on its activity, the concentrations aimed at can only be reached by recycling of biomass to the fermentor by membrane filtration. This study will hopefully lead to the development of integrated membrane bioreactors adapted primarily to waste water treatment, and possibly to other industries involving fermentation.

The existing production facilities for membranes and modules will not be able to fulfill the demand from the market if this project becomes a success. This means that completely new facilities have to be built especially for the membrane production. These types of facilities are quite complicated and consist of very complex units. The planning and construction are estimated at approximately three years from the decision stage till the first usable membranes are produced.

This EUREKA project includes the building of fullscale test and demonstration plants for the production of drinking water, purification of waste water, or even total recycling, partly to prove the general applicability of the processes and partly to solve the special wishes/problems of the clients. the authorities of the different countries or even regions will ask for data to be submitted for approval before any plants can be sold and put into operation. Such demonstration plants are scheduled to be in operation within 5 years.

CONCLUSIONS

Membrane filration plants present clear advantages over conventional water treatment techniques. They will help to produce a water of better quality, will be less expensive, more compact, easier and more reliable to operate. They will also open the door to advanced biotechnology, resulting in turn into further improvements. They will, in other words, be a determining tool for giving a better service to the consummers. The challenge is indeed very great, but it is definitely whorthwhile to try to meet it !

Membrane separation will undoubtedly be commonly applied in water treatment, by the end of this century.

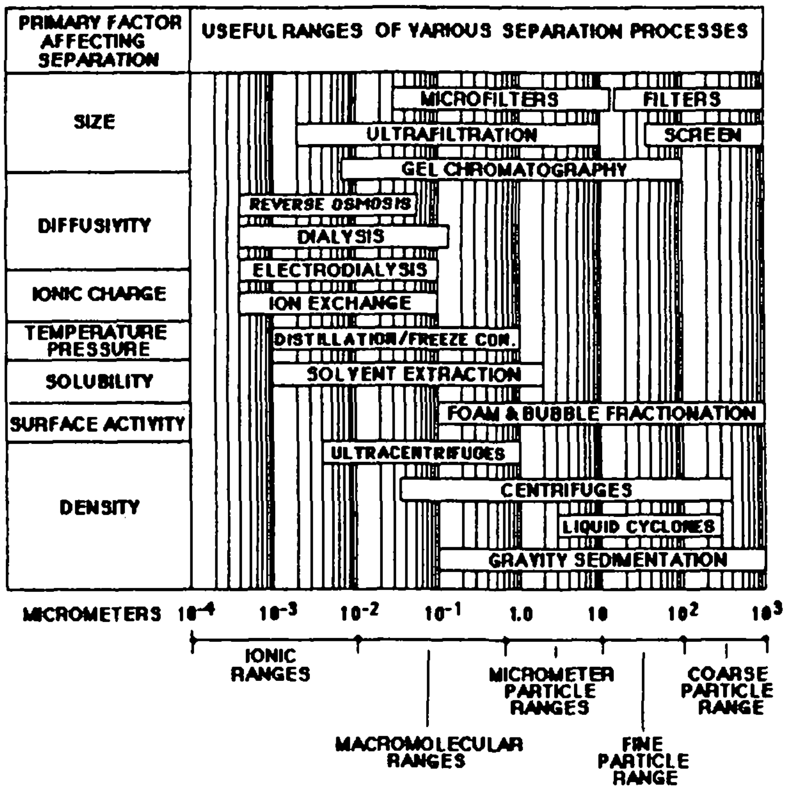

Fig. 1. Useful ranges of various separation processes

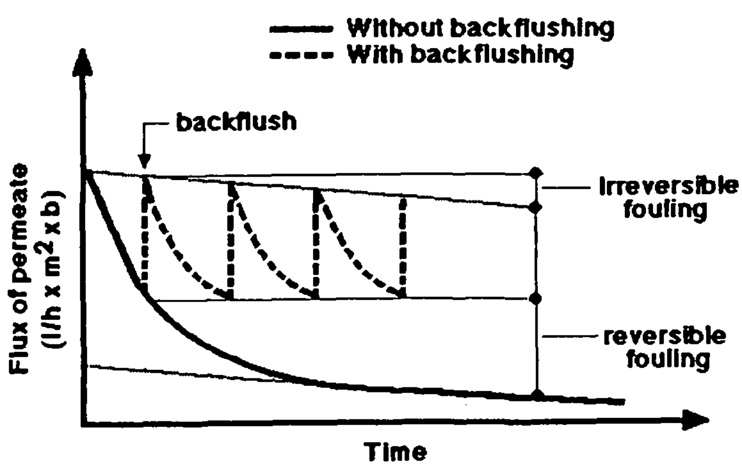

Fig. 4. Theoretical throughput of a UF/MF membrane

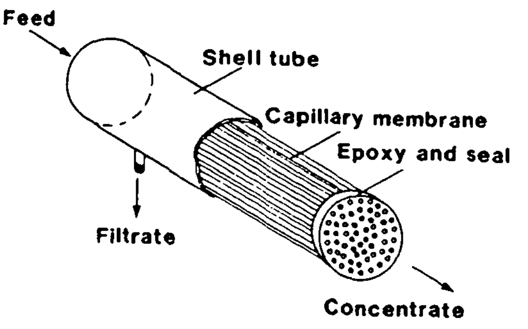

Fig. 2. Schematic of a module with capillary tube membranes

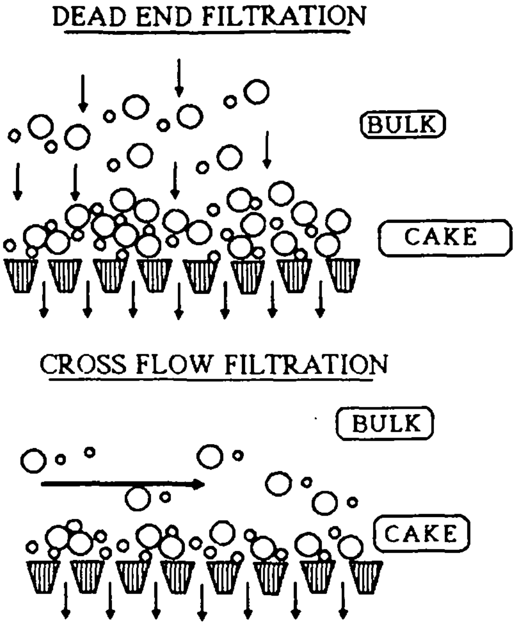

Fig. 3. Gross-flow filtration : the operating modeof UF and MF membranes

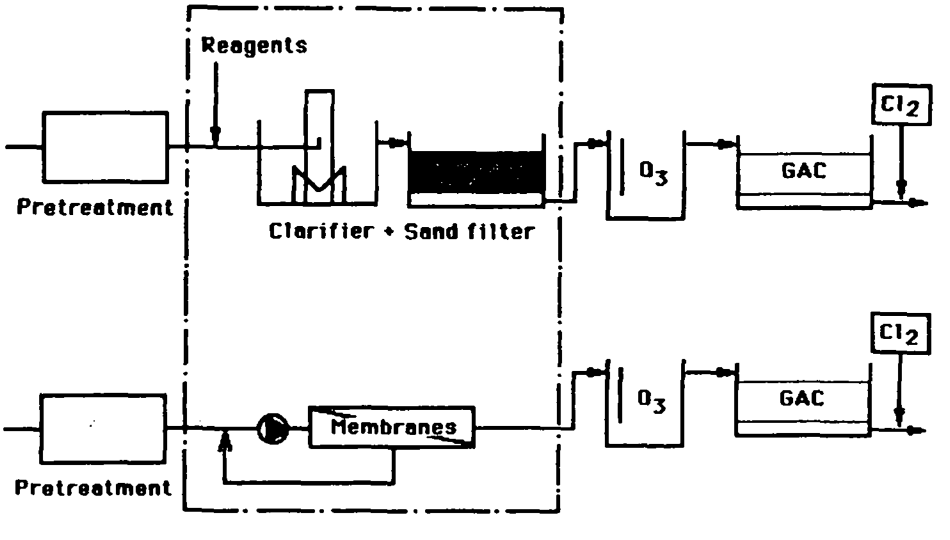

Fig. 5. Position of UF/MF in a clarification line, i.e. in replacement of conventional clarifiers and sand filters

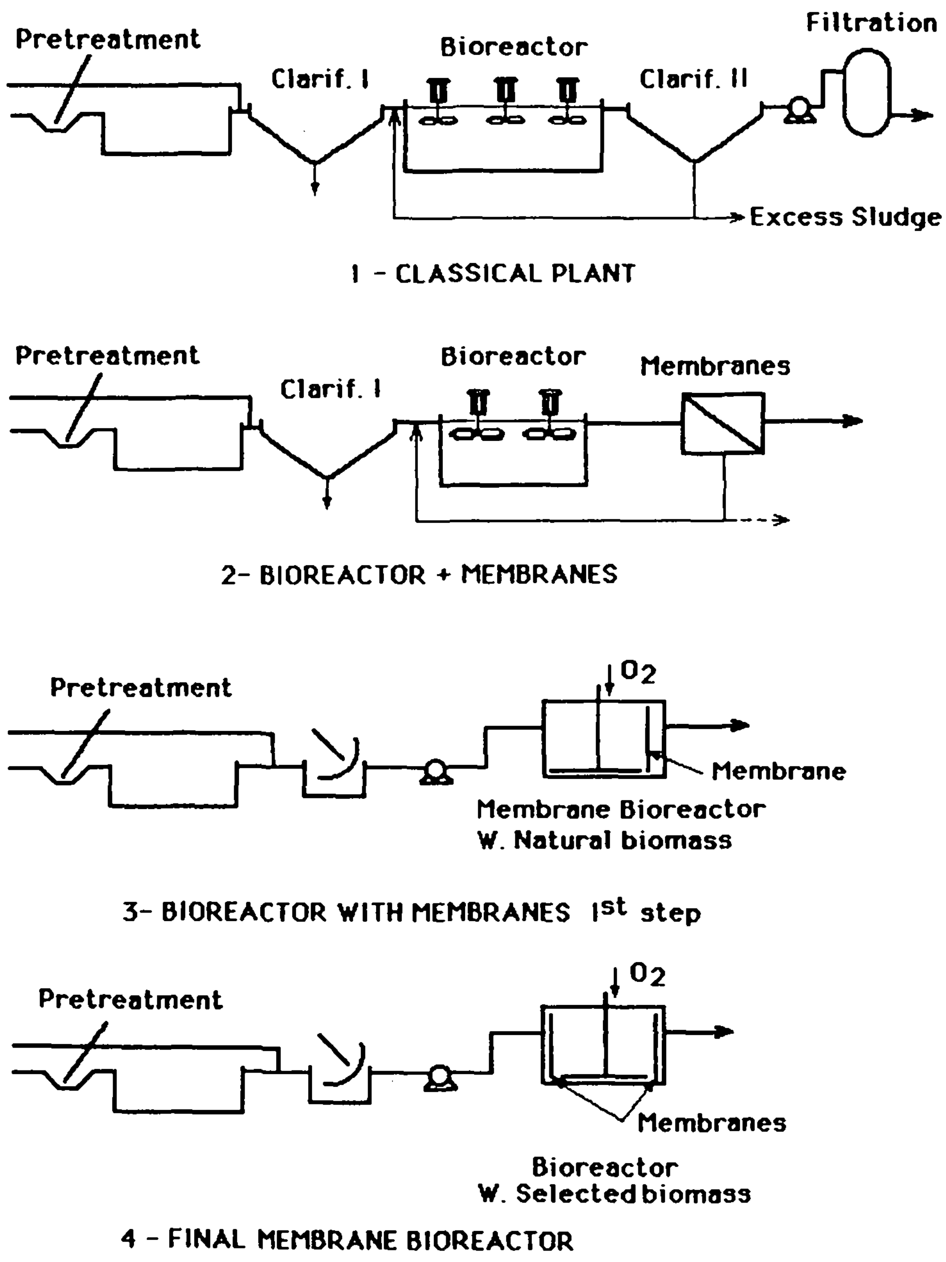

Fig. 6. Trends in waste water treatment technology : the japanese aquarenaissance project toward membrane bioreactors

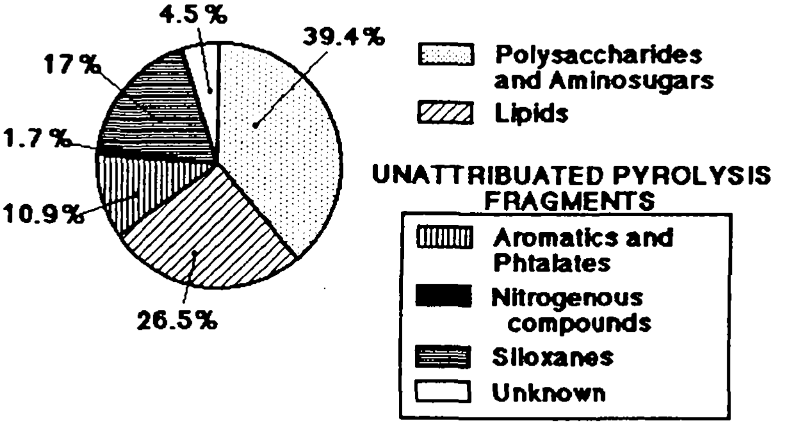

Fig. 7. An example of the composition of foulants in a surface water UF treatment (La Nive, Novembre 1986)

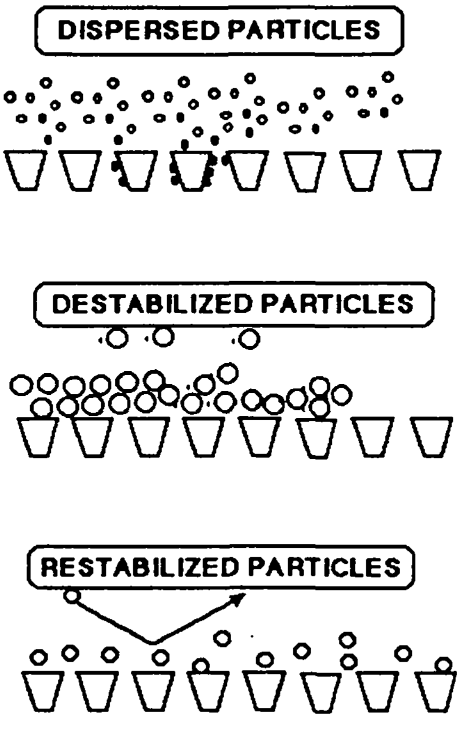

Fig. 8. The different possible stategies for pretreatment before MF separation

CENTRAL WATER SOFTENING WITHOUT WASTE MATERIAL

Cornelis van der Veen
Amsterdam Water Supply
the Netherlands

ABSTRACT

The rapid industrial development confronts the environment with equally rapid accumulation of waste material. This process has to be halted and reversed as the resulting pollution endangers healthy life of men and animals. Technology in the immediate future has to be directed to waste avoiding processes. This applies also to drinking water technology. A method of water softening is presented which satisfies this condition.
Central Water Softening makes it possible to raise the ph of the water, which lowers solubility of metal like lead and copper (in the described case by factors 2 and 5). This improves the quality of the drinking water from the health point of view. Water Softening has economic advantages because of savings on energy, soap, detergents and maintanance of distribution pipes and installations. It has ecological advantages as the waste water will contain less metal, less phosphate and less chloride (because individual water softeners for the greater part become superfluous).
In Amsterdam hardness is reduced from 2.5 to 1.5 m mol/l (1 unit is equivalent to respectively 100° US/UK= 100 ppm $CaCO_3$, 5.6° D German Grade or 10° F French Grade). The softening process consits of adding caustic soda, which crystallises on seeding grains in a fluidized bed in cylindrical reactors. The increase in sodium concentration is small, keeping the water quality within regulatory guidelines. The only by-product are the marble covered grains (1 to 2mm) which are reused in industry and agriculture.
There is no waste.
In this case the cost of softening is US$ 4, the savings are estimated at US$ 30 per household per annum.

KEYWORDS

Central water softening; health; environmental, aesthetical and economic aspects; crystallisation in fluidized bed; reactor design; process regulation; seed material; recycling of marble pellets.

FUTURE DEVELOPMENT

The industrial countries are witnessing a tremendous upsurge in production during this age. Industry has succeeded in developing an amazing array of new processes and technologies. Production has increased to an incredible level. The common citizen can buy in shops around the corner what in the past was only in reach for the very rich. This development will continue to the material benefit of the people in those countries.

There are however side effects, which need attention and will need more in the immediate future.
First of all there is great danger that this development will take place at a much faster rate in the industrial countries than in developing countries. This would increase the already sharply distinguishable differences between rich and poor people.

Secondly modern process technologies become more and more labour extensive. They also ask for highly qualified professional people. This results in shortening labour hours and less work for unskilled people. The quick pace with which this development takes place, presents problems as to how to avoid unemployment, how to use the increasing free time and what to do with the unskilled labour and labourers.
In the third place with increasing production there is more and more waste material produced. This is dumped on land and in rivers, lakes and seas and blown into the air.
This pollution problem is probably the worst of all, because of the endangerment of the environment. As man is a product of his environment a change for the worse in his environment will have an adverse effect on him.
Looking back in time, at first pollution was accepted as an unevitable, not too serious byproduct. In the course of this century the industrial countries started to combate pollution by treating waste before releasing it into the environment. Today it is clear this is not a final solution, for two reasons.
Treatmentplants do not remove all pollutants and not everything of each pollutant.
Secondly treatmentplants may fail and then the full amount of waste is discharged during a period.
For the future the only long lasting solution is to be found in clean technologies, in which there is no waste produced. This should not be more expensive. On the contrary: waste means throwing away material that could be used to advantage if one only took the trouble. The history of chemical production is full of examples where processes were improved by reducing the waste and using more of the raw material that was put into the process for making worth wile products.
The water industry does not differ from other industries: sludge is often produced as a waste byproduct of a water treatment. In most of the water softening methods sludge is produced. The fluidized bed system, as presented in this paper however is a clean technology. The calcium removed from the water precipitates in a crystallization process on solid grains, which can be used again in industry and agriculture. There is no waste.
This system can also be used to remove for instance phosphates and heavy metals.
As all industries the water industry should direct its research at the development of clean technologies. Those have the future.
The industrial world should be in the frontline of this development. Processes that pollute the environment will in the future be looked upon as primitive and below standard. Rightly so. If the industrialized countries go ahead in this direction, developing countries could profit and hopefully avoid some of the pollution the Western countries suffer from.
This is not only a question of transfer of technology; there are also cultural aspects. However transfer of technology is an essential element. The system of water softening by fluidized bed method is a perfect example of a clean technology, that has proved its effectiveness and reliability already. In June 1987 softening plants with a total capacity of 115 million m^3 per year were put into operation in Amsterdam, after ten years of research, development and testing on a real scale reactor.
This technology could be used in many parts of the world in the near future, for example the year 2000.

INTRODUCTION TO CENTRAL WATER SOFTENING

The following main reasons make central water softening attractive:

Health
Private softeners carry the risk, in case the water is not chlorinated right up to the consumer's tap, of pathogenic bacterial growth on the ion exchangers being used. When the pH level drops, and is not corrected, the heavy metal solubility of the pipes may increase. If the water is softened in a central controlled system by increasing the pH the lead and copper solubility decreases by a factor of 2-5 (Fig. 1).

Environment
When central softening is applied on a large scale, the amount of phosphate in domestic detergents can be reduced substantially. This will dinimish the phosphate content of effluents. A high phosphate content causes hypertrophic growth of algae in surface waters.

Softening by means of ion exchangers in private households and industry causes waste water to become saline. The higher equilibrium pH of centrally softened water reduces the heavy metal solubility. Sludge and effluent consequently contain far fewer toxic heavy metals and comply sooner with the relevant regulatory regulations, so that it can be re-used as fertiliser.

Energy and Safety
Reduction in mineral scaling following proper central water softening greatly enhances heat transfer in heating appliances, so that less energy is required. Reduction in mineral scaling dinimishes the risk of breakdown in appliances due to faulty reverse valves, check valves, stopcocks, pressure valves, ball cocks etc.

Aesthetics
Softening reduces inconveniences such as grey film, soap scum, wear and stifness of laundry, streaks on dishes, glassware, windows and plants, clogged humidifiers etc. Also some foods and drinks acquire a better taste.

Economics
Savings per household on maintenance costs of water and heating appliances, soap, detergents, energy etc. are a multiple of the cost on central softening. In Amsterdam the total costs of central water softening will be approximately US$ 0.025 per m^3 or US$ 4 per household per year. Total savings per household amount to US$ 30 per year. There is a additional saving on costs as there is less corrosion of metal transportation and distribution pipes of the water supply system.

Summarizing:
- Health:
* it avoids the risk of pathogenic bacteria as in private softeners
* reduced hardeness - higher equilibrum pH - fewer heavy metals in drinking water

- Environment:
* fewer phosphates
* fewer regeneration salts
* fewer heavy metals

- Energy and Safety:
* reduced hardness - less scaling - fewer breakdowns
* less energy consumption

- Aesthetics:
* better taste of some foods and drinks
* fewer smears when cleaning windows, watering plants etc.
* less wear and less stiffness laundry; less soap scum

- Economics:
* cost US$ 4 per household per year
* saving US$ 30 per household per year because of less detergents, energy consumption, maintenance and repairs.

TYPES OF RAW WATER

The raw water used for the production can be ground and surface water. Total and temporary hardness are to be distinghuished. The total or permanent hardness is the hardness caused mainly by various calcium and magnesium compounds such as calcium sulfate and chloride. Temporary hardness is caused by calcium bi-carbonate and magnesium bicarbonate; it is removed by boiling the water. In the Netherlands, total hardness in groundwater ranges from 0.2 to 6.25 mmol/l, and temporary hardness from 0.4 to 12.5 mmol/l. The avarage ratio between temporary and total hardness is generally around 2, but it can range from 1.25 to 2.5. Total hardness of surface water ranges from 1.0 to 3.5 mmol/l and temporary and total hardness is usually about 1, however it can vary from 0.8 to 1.5. The ratio of temporary to total hardness is generally lower for surface than for ground water. This ratio is one of the factors influencing the choice of chemical used. In Amsterdam Water Supply there are two main drinking water treatment plants. One supplies a blend of river (Rhine) and ground (Dunes) water. The other supplies mainly Lake water with a low percentage of river (Rhine) water.
The ratio of temporary to total hardness for the River-Dune water is 1.2, and for the Lake-River water 1.6 to 1.3.

VARIOUS SOFTENING PROCESSES

There are three groups of softening processes:

A ion exchangers
B desalination
C formation and deposit of calcium carbonate by means of raising the pH value.

The first two groups are as a rule too expensive for the production of drinking water. The discharge of their briny effluents raises ecological problems.
In recent years desalination processes using membrances, preceded by a softening process from the third group in order to minimise clogging, have become increasingly cost-effective and are therefore being more widely applied.

The processes of group C can be categorised according to:
- the chemicals used to raise the pH value
- the form in which the $CaCO_3$ is released: either as watery sludge or hard marble grains.

The chemicals are:
- $Ca(OH)_2$ or CaO, lime, calcium (hydr)oxyde (solid);
- NaOH, sodium hydroxyde (caustic soda) (liquid);
- Na_2CO_3, soda ash (solid).

The chemical reactions in each case are given in Fig. 3.
When lime is used, removal of the same quantity of Ca^{2+} requires twice as much HCO_3^- compared with the use of caustic soda. The quantity of calcium carbonate released is also twice as large. Lime is used where the ratio between temporary and total hardness is high. Soda ash is used when the HCO_3^--content, in other words the temporary hardness of the water, is very low. The Na^+ concentration increases twice as rapidly in that case.

In the intermediate range, sodium hydroxide should be used; the sodium content increases only half as much as when soda ash is used. As the ratios of temporary to total hardness occurring in Amsterdam are 1.2 and 1.6 to 1.3 sodium hydroxide will be used. The sodium concentration will increase by about 25 Na^+/l. The sodium content of both types of water will remain below the regulatory norm (120 mg Na^+/l).

The guideline of the European Community of 15 July 1980 permits reduction of total hardness to 1.5 mmol/l, and of temporary hardness tp 0.5 mmol/l. This last figure is too low, in view of the inadequate pH buffer capacity and higher corrosion rate. Temporary hardness levels under 2 mmol/l should be avoided.

Calcium carbonate ($CaCO_3$) can be released either as sludge or as calcite crystals (marble).

There are many precipitation processes in which a floc is formed which then is separated by means of sedimentation. The sludge released usually shows a very low dry matter content of 0.5 - 1%. The sludge can subsequently be thickened and dehydratated, using the available techniques. Barring heat treatment, not much use can be made of such waste material. It will therefore generally have to be dumped.
Because the detention period for flocculation and settling takes much time (0.5 - 4 hours), the installations are voluminous and expensive. Since $CaCO_3$ can be deposited anywhere, a great deal of maintenance is required. As not all of the flocs settle, at least one rapid filtration after sedimentation is necessary. The load of the filtration will in many cases be excessive.

The process in which calcium carbonate can be released is by crystallization on seeding grains as marble. The marble pellets can be used as they are in demand by industry and agriculture. This process as a clean technology is therefore attractive.

CRYSTALLISATION USING SODIUM HYDROXIDE

The addition of caustic soda (sodium hydroxide) causes the pH value to rise. The following chemical reactions occur (Fig. 4):

$$NaOH \longrightarrow OH^- + Na^+ \qquad (1)$$

$$HCO_3^- + OH^- \longrightarrow CO_3^{2-} + H_2O \qquad (2)$$

$$CO_3^{2-} + Ca^{2+} \longrightarrow CaCO_3\downarrow \qquad (3)$$

In this way the ion product of (Ca^{2+}) (CO_3^{2-}) exceeds the solubility product of $CaCO_3$ which is then formed in the homogeneous waterphase.
Although as a consequence of the pH increase the thermodynamic equilibrium is situated at the right side of the equation (reaction 3), the crystallization process occurs kinematically very slow because of the watermantle around the carbonate ion. If the pH or the concentration of CO_3^{2-} increases, the driving force also increases and the precipitation reactions occur in about two hours, as shown in Fig. 5. Crystallization however occurs in 5 - 10 seconds. This results from the property of the exothermic crystallization process by which the watermantle round the carbonate ion can be removed and carbonate and calcium ions can be built in the crystal lattice of marble (Fig. 6).

The essential point is that crystallization proceeds very rapidly at a pH level only 0.3 - 0.4 pH units (SI* = 0.3 - 0.4) higher than equilibrium pH. Whereas softening by means of crystallization occurs very rapidly (5 - 10 seconds) at a very low driving force, the precipitation method takes about 1 hour or more at a pH of as much as 1.0 - 1.5 pH units (SI) = 1.0 - 1.5) higher (Fig. 7).

This crystallization can be used to great advantage in the softening process by adding the caustic soda so homogeneously to the water to be softened that high local pH levels do not occur at any point. In other words, precipitation and the formation of turbidity in the homogeneous water phase are practically, if not completely, ruled out. Turbidity will then increase little, if at all, during the softening process, so no extra load will be presented at any subsequent purification step. The softened water contains practically no seed crystals, which would otherwise cause a white turbidity at boiling temperature (Fig.8).

As shown in Fig. 9, the equilibrium pH value decreases in linear relationship to the temperature. This has been experimentally demonstrated within a temperature of 0 to 45°C. SI levels remain reasonably constant for a given degree of softening. This process can therefore be used effectively for both cold surface waters and warm ground waters. The process takes place in the same manner when soda ash (Na_2CO_3) or caustic soda (NaOH) is used. Soda ash is to be preferred for waters with a very low temporary hardness.

REACTOR

The optimum operation of the crystallazation process requires an installation which meets certain specific, mostly hydraulic criteria.
First of all the raw water must be brought into contact in an upward direction with grains in a fluidized bed, preventing the growing grains from becoming attached to each other and forming agglomerations. In this way optimum seeding conditions are established.
Next, the grains should at all times be properly distributed according to size, those with the greatest seeding capacity situated at the base of the reactor. This has the additional advantage that the grains most developed in size will be nearest to the drainage point (see Fig. 10). To realize this condition, the reactor must be cylindrical. A conical reactor causes greater vertical mixing of the grains which results in a poor distribution of the grains.
In the cylindrical reactor, as in backwashing with rapid filters, a uniform velocity profile over the horizontal cross-section can be achieved by fitting at least 30 filter nozzles per m^2 in the base, allowing water to be fed in from a water chamber. By introducing sufficient resistance over these nozzles it is a fairly simple matter to obtain the required even distribution of water over the base. The very high level of turbulence in the flow of water discharged through the nozzles can be used for the mixing of the caustic soda. As the water moves in upward direction, the flow quickly turns into an upward flow with a uniform velocity profile over the horizontal cross-section of the reactor.
By making a double bottom in the reactor, a chamber can be created for the introduction of caustic soda, which is fed through special openings in the nozzles to caustic soda outlets above the water outlets.
A reduction in hardness of 1 mmol/l (=5.6°D) requires approximately 45 mg NaOH/l. Using a diluted caustic soda solution of 25% density (freezing point = -18°C, see Fig. 11), the caustic soda solution: water ratio is approximately 1 : 8000.
This means a low caustic soda dosage to a large volume of water. This method ensures correct *mixing, that is: all the water is homogenised, or mixed with equal amounts of caustic soda.* This prevents the occurence of high pH levels and the formation of calcium carbonate (turbidity) in the homogeneous water phase.

*) $SI = pH_{crystall.} - pH_{equilibrium}$

It is essential to achieve the best possible crystallization conditions by choosing the optimal number of caustic soda dosage nozzles per m^2 in the reactor base. This will ensure a minimum use of caustic soda and minimise the risk of turbidity and sludge. This minimises the resultant burden on the subsequent purification process. It avoids at the consumer end the whitening of softened water at boiling temperature, and scaling in heating appliances.
These potentially troublesome phenomena can as far as possible be prevented by aiming for an minimum 'Theoretically Depositable Calcium Level' (TDC). Under optimum conditions, this level will have a value of 0.03 - 0.05 mmol/l. The lime-disposing capacity is then 3 - 5 mg $CaCO_3$/l at the point where the softened water leaves the reactor. Following filtration the pH level will often be lowered, as well as the lime-disposing capacity (to around 1 - 2 mg $CaCO_3$/l).

A number of experiments were undertaken to get some insight into minimum TDC levels. One of these experiments was carried out in a reactor with a diameter of 2.6 m. Inside the double bottom 187 water inlet nozzles were provided, with caustic soda dosage points, which could be closed by means of removable tubes. By removing these closure tubes progressively in concentric circles, the total number of caustic soda dosage points was increased in stages from 9 to 187, while the reactor remained in constant operation. It was found that minimum TDC and minimum increase in turbidity occured when a total of at least 120 - 125 open dosage nozzles were used, or 20 - 25 nozzles per m^2. The non-homogeneous results with insufficient open nozzles per m^2 are shown in Fig. 12, which gives pH and total hardness TH as monitored at four points, at various levels in each case. The tests were performed at a water temperature of 5 - 6°C for an upward waterflow of 430 - 600 m^3/h.

The nozzles are constructed in such way that caustic soda solution is streaming out of three openings in the top of each nozzle in an area with still-standing water. In this way a cloud of caustic soda solution around the top of the nozzle is formed (see Fig. 13). The outer parts of this cloud continuously come in upward streams and are mixed with water. In this area there are no solid parts of the reactor, on which calciumcarbonate can deposite. There are only seeding grains, which grow in size by crystallization.
To prevent the hard water of contacting the caustic soda outlets in the nozzle top and to prevent clogging, an area with still-standing water around the top of the nozzle is needed. This is obtained by the positioning of each nozzle in relation to the surrounding nozzles.
Each nozzle is surrounded by six other nozzles and each nozzle has six water outlets. The nozzles are moreover placed in such a way that the water jets are not directed towards the surrounding nozzles but to the centre points in between neighbouring nozzles. In this way three water streams bump against each other in these centre points and move then in a perfect upward direction.
These design requirements are very important for the prevention of clogging by unwanted deposits. About 100 tonnes of marble ($CaCO_3$) per square meter of surface area of the base are produced annually in this way in the shape of marble pellets. Deposits at unwanted points can rapidly cause a breakdown. The design is worked out to avoid this under all circumstances.

In the case of large diameter reactors, it is advantageous to allow for drainage of the pellets at a number of points (1 per 1 to $2m^2$) in the base in order to ensure that the pellets are as evenly sized as possible. The drainage operation can easily be automated and geared to the bed weight.The drainage periods must be kept short to allow the bed to reclassify.
The grain size at the bottom of the reactor can be controlled by introducing new seeding material with an ejector approximately 1 metre above the base. Through the increased weight of the bed the biggest pellets are then removed. In this way the seeding material can be brought in without disrupting the introduction of water and caustic soda.
When sodium hydroxide is introduced into the water, three phases can be distinguished:

- the chemical reaction: $OH^- + HCO_3^- \rightarrow CO_3^{2-} + H_2O$
- the Ca^{2+} and CO_3^{2-} ions are transported to the crystallising surface on the grains
- crystallization takes place, in other words, the Ca^{2+} and CO_3^{2-} ions are incorporated into the crystal lattice

The third phase, crystallization, takes longest, and therefore determines the speed of the entire operation. This can be expressed in the amount of hardness bonded by crystallization per surface unit of the seeding grains per unit of time. This specific crystallization surface is determined by the diameter of the grains and the specific gravity of the grains and the water, and thus by the temperature of the water (see Fig. 14).

The softened water can be discharged by means of an overflow or in case of a closed reactor, by means of a central outlet in the top of the reactor. A conical part of limited size at the top end of the cylinder serves to prevent the very fine particles of seeding material from being drained off with the water flow.

PROCESS

Depending on demand, the rate of flow of water through the reactors can be adjusted without difficulty from 50 to 150m/h. The caustic soda solution dosage is regulated in proportion to the discharge, the set point being indicated simply by the pH value of the softened water, which at a given temperature produces the desired end hardness.
There is a negative correlation between the pH level and the temperature for the production of a given end hardness (Fig. 9). In other words, for a given target hardness, there will be a specific pH equilibrium for any given temperature. In order to achieve the target hardness, however, a specific driving force will also be required. This can be expressed in TCD, or as SI*, where pH crystall. is a direct instrumental control parameter.

It can financially and technically be attractive to use a partial-flow or split-treatment softening process to soften water beyond the target level for subsequent mixing with unsoftened water.

To achieve optimal softening conditions a certain fixed height of the fluidized bed is necessary. Figure 15 shows that a minimum height of 2m is necessary to obtain the lowest possible total hardness for a given pH value. Knowing the height of the reactor and the height of the fluidized bed in the reactor, the total pressure at the basis of the reactor can be calculated for a given average size of the seeding grains. In Appendix 1 this has been done for the Amsterdam water softening reactor.
This pressure can be checked during the operation and used for the automatic regulation of the drainage values. The duration of drainage at each drainage point should not exceed about five seconds, to avoid draining off sand from further up the fluidized bed. After a short drainage period the bed will automatically regrade itself above the drainage point. The frequency of the drainage cycle can be set to something between 3 and 6 times a day, depending on the water discharge and the amounts of $CaCO_3$ removed.

If no new seeding material were to be introduced, the weight of the fluidized bed would increase to its maximum, at which point the drainage cycle starts automatically. The total number of grains would under that condition drop, as their diameter increases, thus reducing the specific surface area. The diameter of the grains and specific surface area can be maintained at optimum size however, by introducing a suitable amount of new seeding material every one or two days. The optimum grain diameter at the bottom of the reactor depends on the temperature. At very low temperatures, for example 0.5°C, it is 0.85mm, rising to 1 or 2mm at higher temperatures. As a result, the weight of the quantity of introduced seeding material can vary between a percentage of 20% and 2% of the quantity of the removed pellets.

The cost of seeding material should be considered against the potential saving of caustic soda solution.

Since the viscosity of water increases as its temperature drops, the minimum size of the seeding material must be adjusted upwards at lower temperatures to prevent the smallest grains of the material from being swept away with very rapid water flows. In general, the seeding grains should be as small as possible, in order to maximise the potential diameter growth of the pellets before drawing them off. This reduces the cost of seeding material to a minimum. The maximum allowed size of the pellets at draw-off point is determined by the need to minimise expenditure on caustic soda solution and acid. It is necessary to allow for such maximum size so that subsequent purification stages do not suffer from an too high calcium load and also that no problems occur because of scaling (mineral deposits) and whitening of boiling water at the customers end.

In Amsterdam sand grains are used, but in general various seeding materials are suitable, such as:

*) $SI = pH_{crystall.} - pH_{equilibrium}$

material	specific weight in KN/m^3
- quartz sand	26.6
- silver sand	26.6
- garnet	41.0
- marble chips	28.4
- Jurassic bead	27.0
- ore concentrate	52.0
- steel grit	76.0

In order to operate with grains of the smallest possible diameter consistent with resistance to the highest water flow rates, preference is to be given to material of the highest specific volume weight. Steel grit would appear to be the best choice, but it is unsuitable because of its magnetic and corrosive properties. Ore concentrate, on the other hand, has almost no magnetic properties. Garnet has a reasonably high specific weight combined with a strong initiating effect on crystallization, as do Jurassic bead and marble chip grains. The price of garnet is a multiple of that of other materials, but far smaller quantities are required. The other materials are obtainable in any desired size. The eventual choice of seeding material will be strongly influenced by the specifications for marble pellets required by the highest bidder.

Crystallization softening with caustic soda is on the whole, a simple process with little risk of breakdown. The run takes about 5 - 10 seconds, giving stable results at temperatures between 0 en 45°C. Apart from the supply of caustic soda and the removal of sold pellets, the process can be completely automated without difficulty and carried out with a minimum of supervision. Monitoring for about 10 minutes per reactor every one or two days will be sufficient.
This makes the process easily applicable for unmanned pumping stations. Where wide temperature fluctuations occur, some adjustment may be required in the split-treatment softening process and/or the quantity of seeding material introduced.

Reactors need servicing once every two or three years. This entails emptying the reactor, cleaning it with acid, restoring the contents and putting the reactor back into operation. The maintenance operation takes about two days per reactor.

The softening process does not impose any extra load, in terms of intensity or duration, on any subsequent purification process, such as rapid filtration. For instance in a system consisting of rapid filtration, softening and activated carbon filtration, a running time of 2-3 months was attained between two backwashings of the carbon filters.
In comparative experiments on systems with and without a softening stage, no difference was found in the lime content of the carbon in the subsequent activated carbon filtration treatment plant. Care must be taken, however, that dust is released from the seeding material.

After-treatment poses little or no problems and requires no extra facilities. Therefore no extra costs are involved in this part of the process. Actually costs are saved because there is no sludge produced and therefore no need to process this. Because subsequent rapid filtration and/or slow sand filtration usually produces a slight drop in the pH value, little or no correction of the already low pH is needed.

Softening by crystallization with caustic soda can be carried out on raw or pretreated water, on condition that the free orthophosphate content does not exceed 0.5 mg/l. A higher content would produce a soft grain with a more limited seeding effect; to avoid this prior dephosphatation would be required.
The crystallization process actually removes a considerable quantity of phosphate (about 50%), in addition to almost all the heavy metals (in the region of 100%), much of the bivalent iron (70-100%) and all the bivalent manganese (100%). Removal of magnesium and of organic matter is negligible (about 5%).

Pumping stations sometimes have limited storage capacity for the finally produced drinking water. Depending on the variation in demand within the 24 hour period, it may be necessary to stop and start one or more of the reactors at regular intervals. Since the reactor described in this paper has open connections between the water and caustic soda outlets, measures must be taken to ensure that no calcium carbonate is deposited in the outlets, where it could cause clogging. Good results have been obtained in this respect with various methods. One way for example, is to stop the caustic soda feed about twenty seconds before stopping the water flow, to allow for a certain amount of rinsing. Other options are to stop the water flow and leave a concentrated caustic soda solution in the bottom of the reactor (the opposite of the first method); to substitute demineralised water for the solution in the caustic soda solution chamber; or to keep a small circulation flow in operation in the reactor during shutdown.

Whichever alternative is chosen, the softening process recommences immediately on start-up, without putting any extra treatment load on the following purification stage.

PROCESS EVALUATION

The crystallization process for the softening of various raw water types can be done by using chemicals as Na_2CO_3, NaOH, $Ca(OH)_2$. The choice depends on various factors.
Variations in the ratio of temporary to total hardness in the Netherlands can be considerable. Where the ratio is low, softening can be achieved by dosing the water with dissolved soda ash. The process is completely analogous to the process described in this paper with caustic soda. If the ratio is high, a lime softening process is to be recommended.
In the intermediate range, caustic soda can be best used. At either extreme of the intermediate range, the choice of method is also affected by many other factors (e.g. temperature). In the Netherlands the temperature of ground water is usually around 10°C, while surface water temperatures can range from 0 to 23°C. At very low temperatures, between 0 and 5°C, crystallization with lime gives very poor results if any, so that a lime process is in fact inapplicable to the softening of surface water. Another important factor is the requirement that the end product conforms to the regulatory quality standards. Apart from these legal and technical constraints on the process, the choice of the process depends on the following factors:

End quality of water from the pumping station, during distribution and from the tap:
- the pH, as it affects the heavy metal solubility
- the HCO_3^- content, as it affects:
* heavy metal solubility
* cast iron corrosion, i.e. turbidity
* pH buffer capacity, drop in pH.
* formation of white turbidity on heating/boiling
* scaling (mineral depostis) in heating installations (boilers, geysers)
* sodium content.

Costs of softening process:
- investment
- chemicals
- subsequent filtration
- wash water/sludge processing
- operation

Process stability, operational reliability:
- risk of clogging
- frequency of servicing
- process regulation in terms of continuous/non-continuous operation and manned/unmanned operation

Effects on pipe materials
- copper, more pitting at lower (HCO_3^-)
- lead
- zinc; brass, more dezincing at lower (HCO_3^-), zinc-coated steel
- cast iron
- concrete
- asbestos cement.] if SI is higher than 0.

Acknowledgement
The design of the Amsterdam Water Supply central softening reactors and the necessary research were directed by dr. A. Graveland and ir. W.L. Prinsen Geerlings.

APPENDIX 1

Calculation of the pressure at the base of the reactor

In case of the reactors in use by Amsterdam Water Supply the height of the water column inside the reactor is 5 m and the thickness of the bed in its unexpanded unfluidized state is 2 m.
The volume weight of water is 10 k N/m^3.
The specific weight of sand is 26.5 k N/m^3.
In the fluidized bed the sand grains occupy 62.5% of the volume, which means that the volume weight of the sand in dry condition is $0.625 \times 26.5 = 16.6$ k N/m^3.
The weight of one 5 m high column with 1 m^2 cross section is $5 \times 10 + 2 \times (16.6 - 10) = 50 + 13.2 = 63.2$ k N/m^3.

This pressure is independant of the waterflow through the reactor.
In the water chamber underneath the base with nozzles the pressure has to be higher to overcome the drop in pressure caused by the nozzles. This drop in pressure is a function of the flow rate and depends on the size of the grains (figure 16).

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FIGURE 1

Solubility of copper, lead and zinc after 16 hours shut-down in test tube.

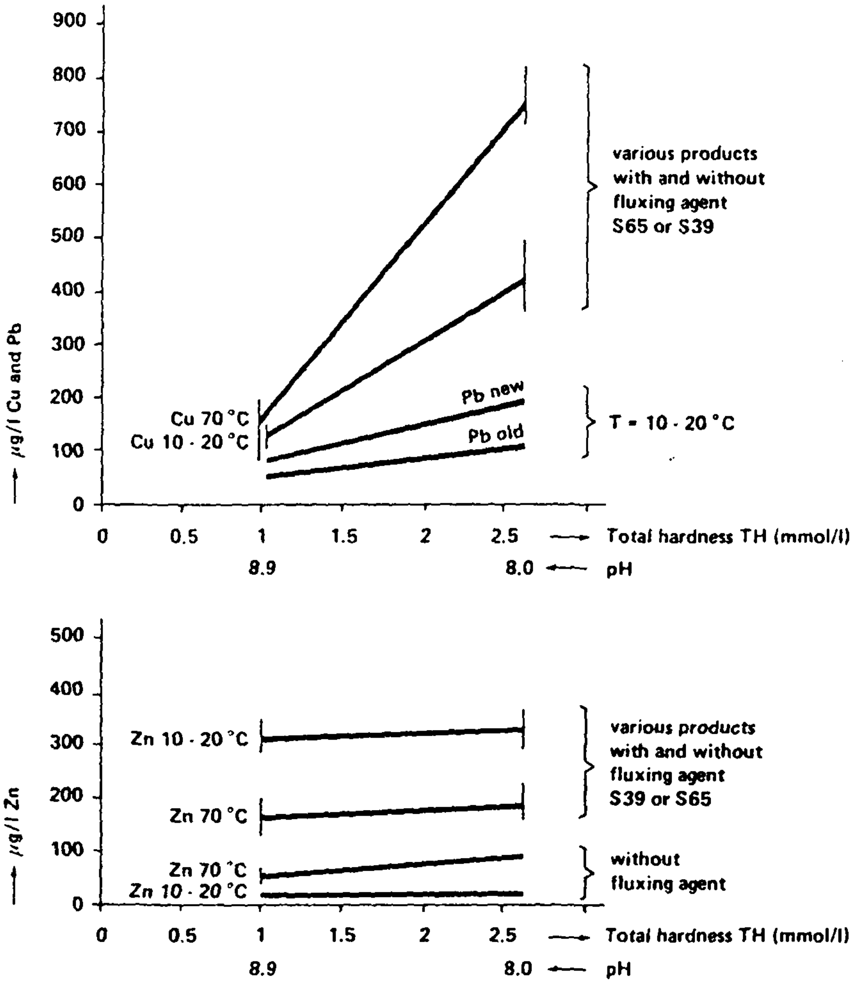
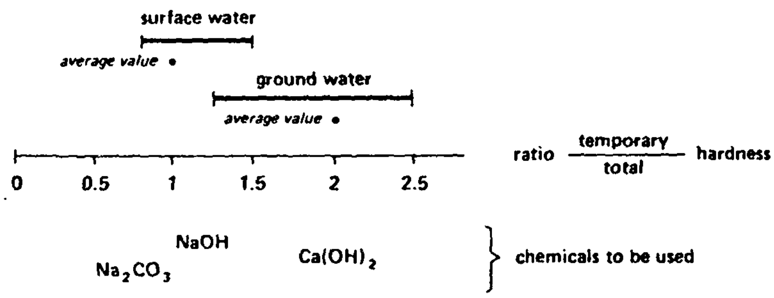


FIGURE 2

The total and temporary hardness of various types of ground and surface water in the Netherlands and the chemicals best used for softening.



in mmol/l	total hardness	temp. hardness	temporary/total	
			limits	average
ground water	0.2 - 6.25	0.4 - 12.5	1.25 - 2.5	2
surface water	1.0 - 3.5	1.5 - 4.0	0.8 - 1.5	1

FIGURE 3

The chemical reactions after introduction of the relevant chemicals into the water.

a.	$Ca(OH)_2$	$\rightarrow$	$2\,OH^- + Ca^{2+}{}_{Ca(OH)_2}$
	$2\,OH^- + \underline{2}\,HCO_3^-$	$\rightarrow$	$2\,CO_3^{2-} + 2\,H_2O$
	$2\,CO_3^{2-} + Ca^{2+}{}_{Ca(OH)_2} + \underline{1}\,Ca^{2+}$	$\rightarrow$	$\underline{2}\,CaCO_3 \downarrow$
b.	$NaOH$	$\rightarrow$	$OH^- + 1\,Na^+$
	$OH^- + \underline{1}\,HCO_3^{2-}$	$\rightarrow$	$CO_3^{2-} + H_2O$
	$CO_3^{2-} + \underline{1}\,Ca^{2+}$	$\rightarrow$	$\underline{1}\,CaCO_3 \downarrow$
c.	Na_2CO_3	$\rightarrow$	$CO_3^{2-} + 2\,Na^+$
	$CO_3^{2-} + Ca^{2+}$	$\rightarrow$	$\underline{1}\,CaCO_3 \downarrow$

FIGURE 4

The changes in the content expressed as a percentage of CO_2 (H_2CO_3) / HCO_3^- / CO_3^{2-} as a function of pH.

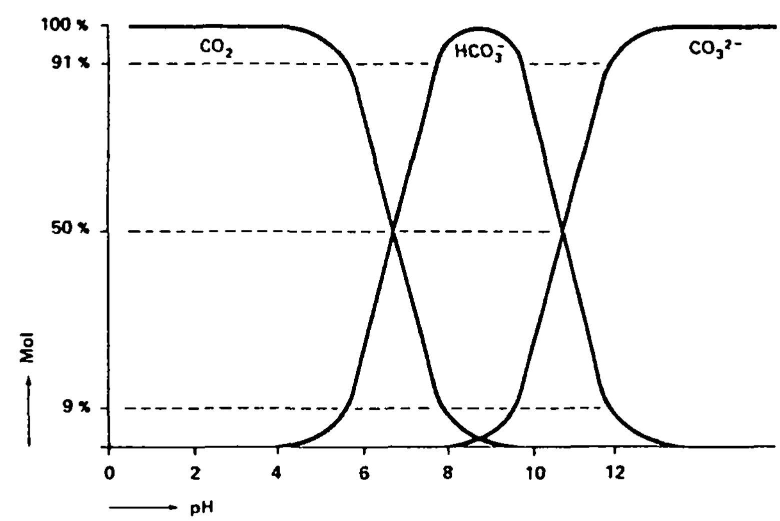


FIGURE 5

Rate of crystallisation and precipitation at a given temperature for the pH values as indicated.

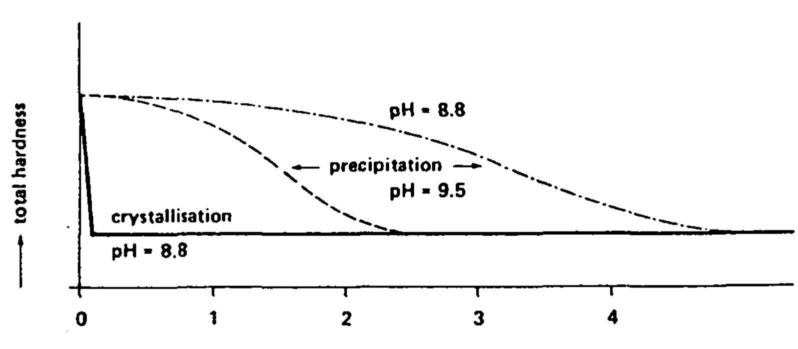


FIGURE 6

The energy level of the CO_3^{2-} ion and the Ca^{2+} ion as a function of the distance to the crystal surface.

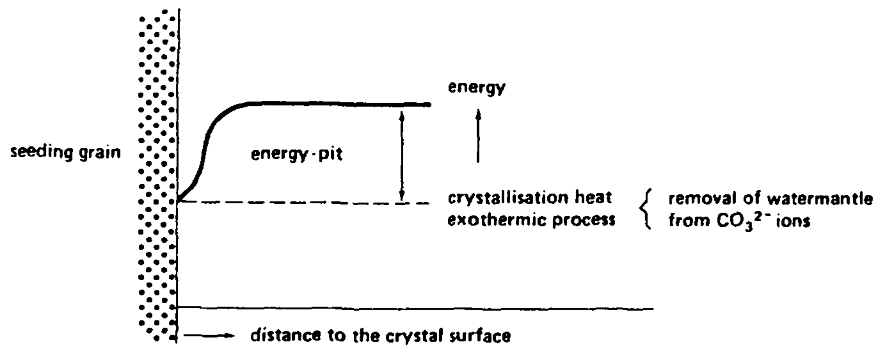


FIGURE 7

Crystallisation with NaOH.

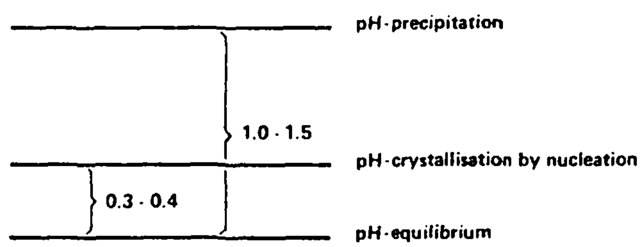


FIGURE 8

Turbidity in JTU before and after 5 minutes boiling of hard and softened water; the ratio of scaling in two identical boilers fed with hard and softened water.

Turbidity in JTU

Hard water boiled 5 minutes		Softened water boiled 5 minutes	
before	after	before	after
0.15	2.1	0.15	0.28
0.14	2.2	0.19	0.35

Ratio of scaling in two indentical boilers after four years

Hard water	Softened water
3.5	1

FIGURE 9

Equilibrium pH and crystallisation pH as a function of the temperature for various hardnesses and flow rates.

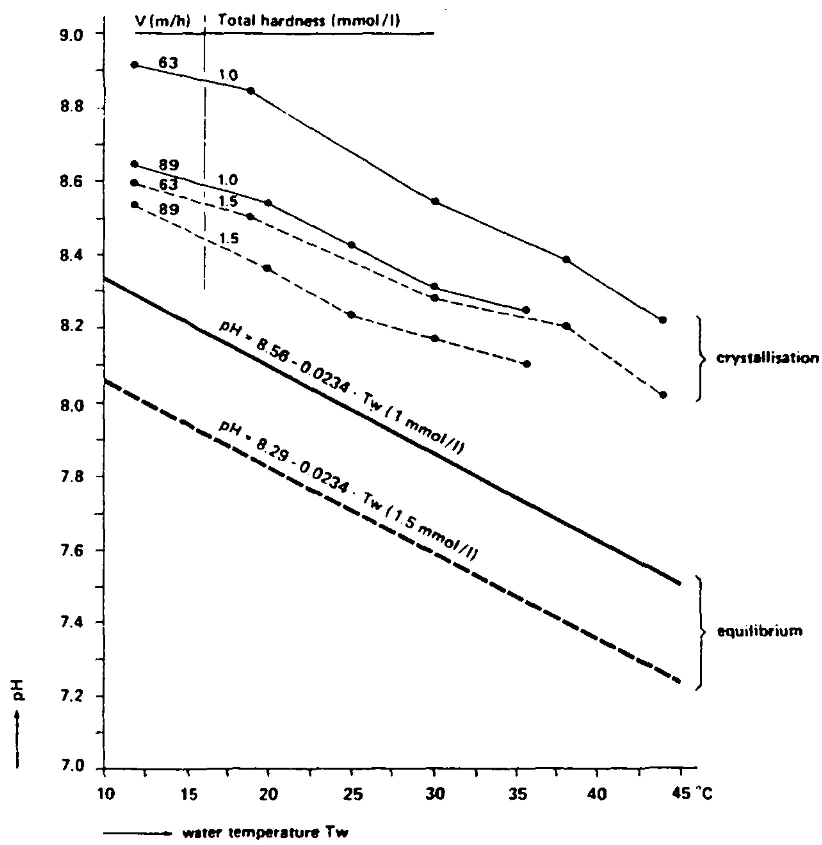


FIGURE 10

Cross section of the Amsterdam water softening installation.

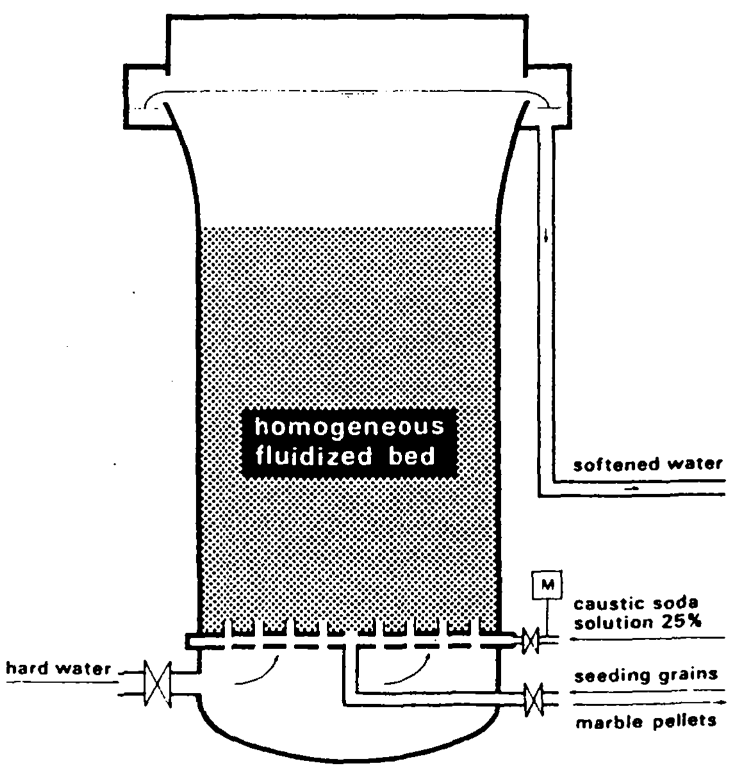


FIGURE 11

Freezing point as a function of the weight percentage of NaOH.

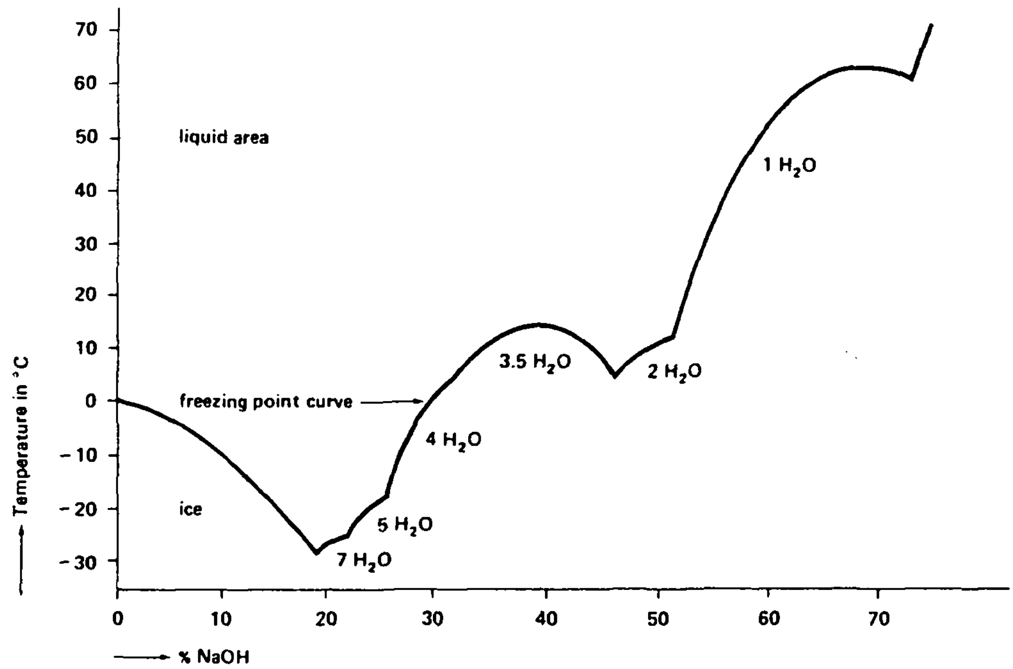
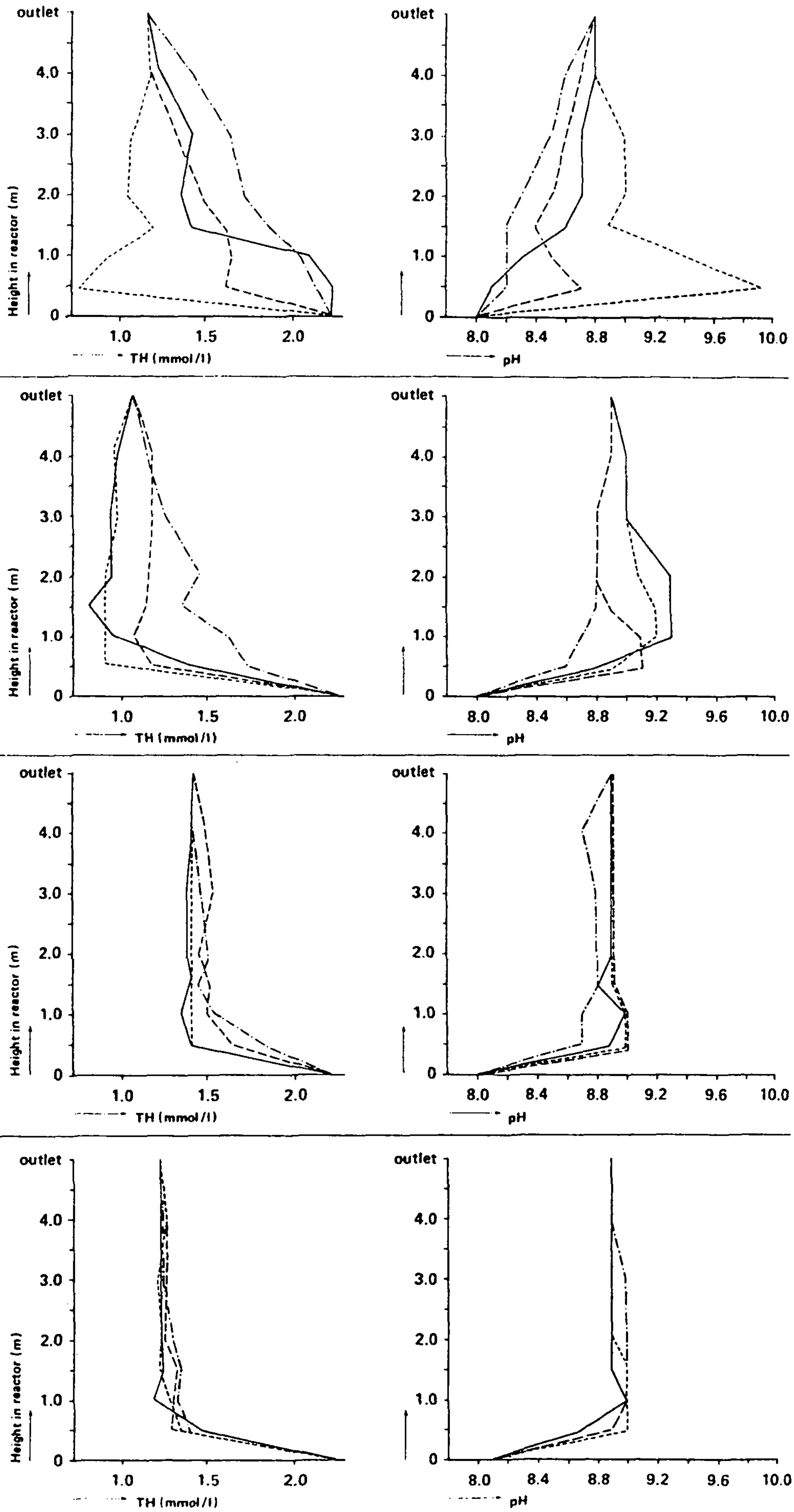


FIGURE 12

Total hardness TH and pH measured at different points along four verticals around the reactor as a function of the height and the number of nozzles.



Q water: 430 m³/h
Temperature: 5.1 °C

1.7 nozzles/m²
(9 nozzles)

Q water: 580 m³/h
Temperature: 6.5 °C

7.0 nozzles/m²
(37 nozzles)

Q water: 600 m³/h
Temperature: 6.3 °C

16.4 nozzles/m²
(87 nozzles)

Q water: 590 m³/h
Temperature: 6.4 °C

35 nozzles/m²
(185 nozzles)

FIGURE 13

Construction of a nozzle, dispersing hard (raw) water and caustic soda in the reactor.

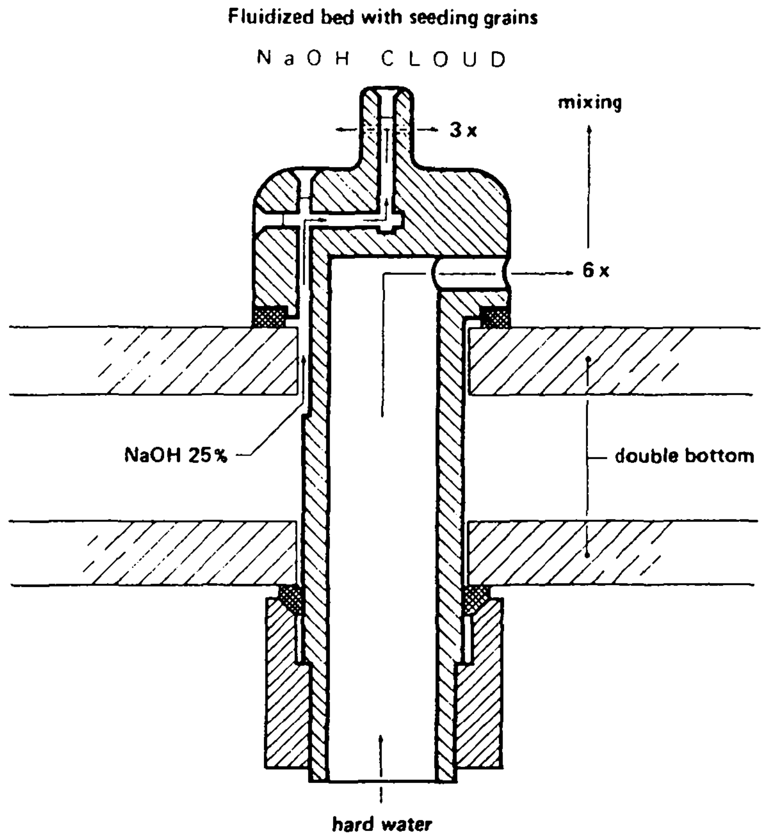


FIGURE 14

Specific surface (surface of all the seeding grains per m³ fluidized bed volume) as a function of the grain diameter at various temperatures; v = 90 m/h.

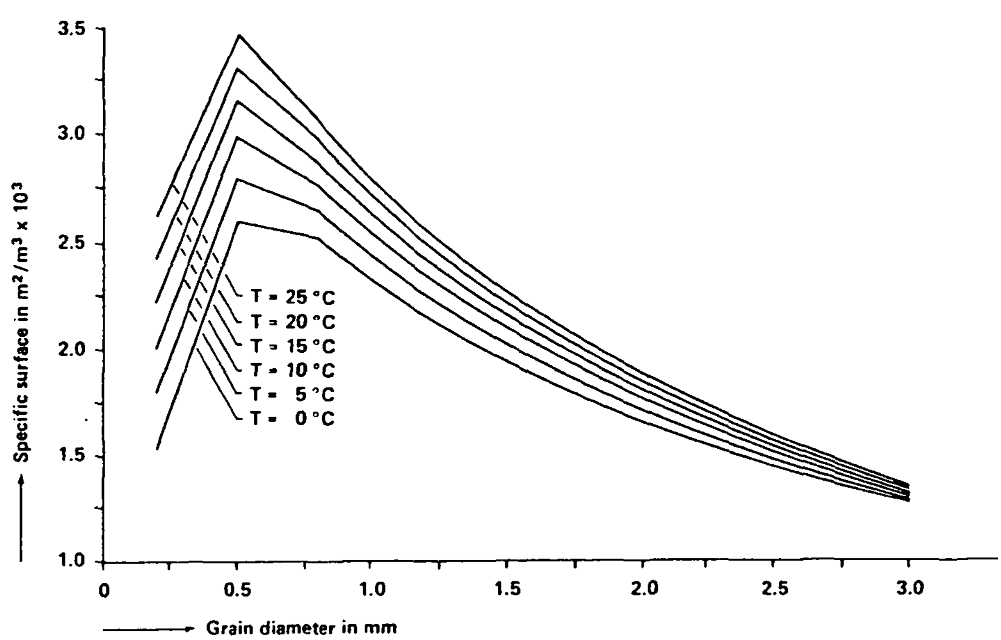


FIGURE 15

Total hardness TH (in mmol/l and °D) as a function of H_{fixed} at constant temperature.

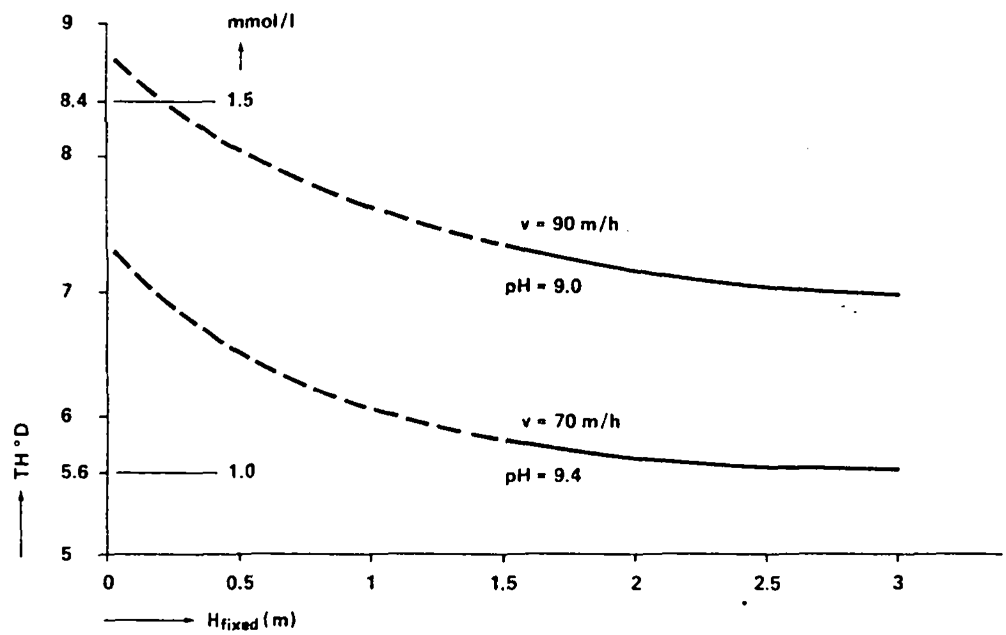
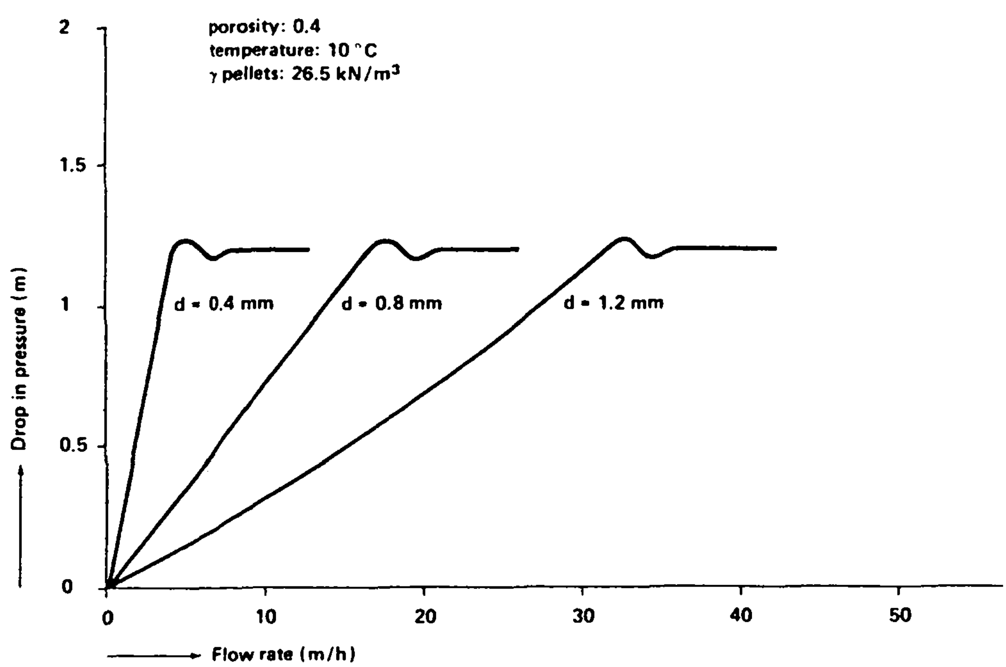


FIGURE 16

The drop in pressure over the bed, or just above the base, as a function of the flow rate at different grain diameters (d).



SESSION 6
SEANCE 6

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- Expert-Systems : New Instruments for the Water Engineers

  Les Systèmes Experts : Nouveaux Outils pour les Traiteurs d'Eau

  A. Santoni, R. Sobral, P. Fontaine, E. Brodard

- Expert Systems for Chemical Laboratories

  Systèmes Experts pour laboratoires chimiques

  J. T. Groennou

Discussion

LES SYSTEMES EXPERTS : NOUVEAUX OUTILS POUR LES TRAITEURS D'EAU

A. Santoni*, R. Sobral*, P. Fontaine*, E. Brodard**

*Laboratoire d'Automatique Avancée de Compiègne - Lyonnaise des Eaux
27 rue de Senlis 60200 Compiègne, France

**Centre de Recherche Lyonnaise des Eaux - Degrémont
38 rue du Président Wilson 78230 Le Pecq, France

RESUME

Cet article se propose d'étudier la stratégie mise en oeuvre par la Lyonnaise des Eaux dans le cadre d'applications intégrant des techniques de programmation qui mettent en jeu des structures d'Intelligence Artificielle (Systèmes Experts). Différents points sont abordés, notamment les motivations de la Lyonnaise des Eaux à s'engager dans l'utilisation de Systèmes Experts et la méthodologie de développement de ces applications. Deux exemples de projets directement applicables aux métiers de l'eau et en cours de développement au Laboratoire d'Automatique Avancée de Compiègne (L.A.A.C.) sont donnés.

MOTS-CLES

Systèmes Experts, conduite des projets, clarification, automatismes, aide à la conception, Intelligence Artificielle.

INTRODUCTION

Motivations

Des tâches complexes, difficilement formalisables, ont été modélisées par le passé et ceci a été prouvé par des projets tels que Mycin ou Prospector. Ces systèmes ont modélisé des expertises dans des domaines très pointus tels que le diagnostic médical spécialisé ou la prospection minière.

Des nouvelles techniques ont été mises en oeuvre pour le développement de ces premiers systèmes experts tant au niveau du langage de programmation (règles de production, programmation objet,...) qu'au niveau de la méthodologie de développement des applications.

La possibilité de voir une partie de la connaissance d'une société traduite sous forme informatique a ainsi poussé la Lyonnaise des Eaux à s'intéresser à cette branche de la modélisation. Les retombées les plus attendues de ces types de recherche sont surtout :

- l'augmentation de la productivité des travailleurs en "cols blancs" (outils d'aide à la décision, aide à la conception),

- une plus large diffusion des expertises dans le groupe,

- la vente de produits informatiques dont la plus value est du savoir faire de la société (outils d'aide au diagnostic, contrôle de process,...).

Moyens

Pour développer un pôle de compétence et de développement des systèmes complexes, il a été choisi de créer un laboratoire de recherche et développement dans la région de Compiègne (L.A.A.C.).

La mission de ce laboratoire est d'entretenir un niveau technique élevé dans le domaine de l'Intelligence Artificielle, plus particulièrement celui des systèmes experts, de préparer les outils de travaux futurs, et de répondre à un certain nombre de développements à court terme. Le niveau technique élevé ainsi que les recherches concernant les projets avancés sont menés par une équipe de recherche fortement liée à l'Université Technologique de Compiègne.

Il a été choisi d'utiliser un générateur de systèmes experts commercialisé plutôt que de le développer à l'intérieur du groupe de la Lyonnaise des Eaux pour pouvoir consacrer la plupart du temps aux problèmes de design des bases de connaissances ainsi qu'à l'acquisition de celles-ci (c'est-à-dire formalisation des expertises).

Ce logiciel devait répondre à une grande diversité de problèmes (diagnostic, planification, simulation,...) et proposer des solutions techniquement pointues. Ceci nous a conduit à explorer des produits qui proposaient une série de techniques de programmation notamment :

- différentes stratégies de résolution :
    * chaînage avant (contrôle de process,...)

* chaînage arrière (diagnostic,...),

- logique d'ordre 1 dans les règles de production,

- représentation par réseaux sémantiques,

- programmation objet,

- interfaces d'aide au développpement évoluées.

Parmi les outils proposés, ART a été choisi pour des raisons techniques :

- stratégie des résolutions complexes, mécanisme des points de vue,

- intégration très cohérente de l'ensemble des techniques présentes

ainsi que pour des raisons commerciales : plus large diffusion, références industrielles importantes (NASA, American Express,...).

Le hardware nécessaire à ces types de développement est surtout constitué de postes graphiques à haute productivité, type machine LISP, Poste SUN, Appolo, micro-Vax II. Le laboratoire est équipé de deux machines LISP (LMI, Symbolics 3620), d'un micro-vax qui sert aussi à établir un lien avec le reste de l'informatique du groupe et d'un parc de micro-ordinateurs (deux Macintosh plus, un IBM/AT3) pour les développements moins complexes, le portage des applications sur micro-ordinateurs et les besoins bureautiques de l'équipe.

DEVELOPPEMENT DES PROJETS

Il est utile de rappeler ici que le développement d'un outil informatique n'est pas l'affaire d'une seule technique, c'est-à-dire que la modélisation de l'expertise n'est qu'une partie d'un tout. Un outil intelligent l'est d'autant plus si la manière de communiquer est performante. Les interfaces graphiques ou largement interactives (souris, menus, aide "on line") sont d'une importance capitale pour augmenter ou permettre l'utilisation d'un logiciel. Des considérations ergonomiques sont donc à prendre en compte pour la définition des fonctionnalités attendues.

Pour la Lyonnaise des Eaux, il ne s'agit pas de créer des logiciels très intelligents dont l'utilisation serait ardue ou frustrante (le système fait tout, l'utilisateur n'a pas la possibilité d'agir, etc...) mais des outils qui devront servir. C'est pour cela qu'une approche maquettage (en fait, définition précise des fonctionnalités) intervient. Elle permet ainsi la rédaction d'un cahier des charges en collaboration avec les experts.

Les étapes du développement d'un projet vont maintenant être décrites, à savoir l'évaluation, le maquettage, le modèle "beta test" et le module opérationnel.

Evaluation du Problème

C'est une familiarisation avec le problème pour pouvoir évaluer l'intérêt et la faisabilité d'un projet. En deux à cinq rencontres avec celui qui propose le projet et souvent un expert du domaine, il est possible :

- de choisir un sous problème représentatif (par la suite, il s'agira de prouver la faisabilité du problème global en résolvant ce sous problème).

- de caractériser le problème : il s'agit d'avoir un ordre de grandeur du nombre des solutions, du type de recherche à effectuer dans l'espace problème, des types d'opérations qui agissent dans l'espace problème, de la longueur des chemins entre un état initial et final, des types de données présentes, etc...

- d'essayer de caractériser le raisonnement hypothétique à partir des buts, etc...,

Le but de cette phase est :

- d'évaluer le temps nécessaire au maquettage,

- de savoir avec quel outil le développement sera effectué,

- de savoir sur quel type de machine (micro, mini, gros système), la version opérationnelle pourra être implantée,

- de donner une idée assez précise de ce que fera le système.

Ceci doit donner lieu à un rapport et la suite du projet sera décidée en fonction de l'intérêt que l'on aura à poursuivre.

Maquettage

C'est la première phase du développement proprement dit, ainsi que celle de définition précise des fonctionnalités du système final. Pour des applications peu complexes, elle prend entre un et quatre mois de travail à l'équipe d'informaticiens.

Le travail est effectué en constante interaction avec l'expert (une demi journée par semaine en moyenne) bien qu'au début le rythme des interviews soit beaucoup plus élevé (une à une journée et demi par semaine).

Cette phase conduit à :

- Un modèle du raisonnement de l'expert concrétisé par une certaine architecture de la base des connaissances (un programme qui sur un nombre limité de cas est en mesure de montrer une stratégie qui le mène à la solution).

- Une définition précise des fonctionnalités, c'est-à-dire un bon aperçu de ce que seront les interfaces utilisateurs, les différents écrans, les valeurs autorisées aux différents paramètres, etc... (l'idéal étant une première version de la documentation utilisateur si c'est un système interactif).

- Une définition précise des différents modules qui composent le système, c'est-à-dire les fonctions qu'ils remplissent, et la manière d'implémenter ces fonctions.

- Une documentation concernant la base des connaissances : les différentes règles, à quoi correspondent les différents objets, un glossaire des termes utilisés.

- Un jeu d'essais représentatifs du problème pour pouvoir tester le modèle et le système.

- Une évaluation précise de la mise au point et en place du module sur test : réécriture, insertion dans l'informatique existante (si besoin).

Ces différents points sont concrétisés par :

- la maquette de démonstration,

- le rapport d'avancement,

- la documentation : technique (programmation, base des connaissances), utilisateur,

- l'évaluation du travail nécessaire pour la phase "beta test".

Cette étape terminée commence le "beta test".

Beta Test

Dans cette phase le système doit être en mesure d'être utilisé par des utilisateurs finaux ainsi que par les experts qui ont aidé à le concevoir. Il est néanmoins indispensable que le concepteur du système participe à cette étape car il devra participer au raffinement des connaissances, ajouter de nouvelles règles, objets ou en modifier. C'est aussi une phase de formation pour le responsable de l'application sur site opérationnel. Des protocoles (fiches de plainte) doivent exister pour pouvoir répertorier les problèmes et défauts du système.

C'est une période de trois à six mois destinée à produire :

- un cahier des critiques,

- une évaluation de l'utilité du système.

Les modifications possibles du système sont établies ainsi que leur coût et l'évaluation et le plan de travail du portage opérationnel complet.

Module Opérationnel

Le module opérationnel est le programme complétement intégré (par exemple, il faut communiquer avec un automate, récupérer des données d'un SGBD, etc...).

Les machines sur lesquelles l'application sera implantée sont souvent différentes de celles sur lesquelles elle est développée. Ainsi, parmi les projets du L.A.A.C., il y en a plusieurs qui maquettés sur machines LISP ont été transportés sur micro-ordinateur ou qui ont été "beta testés" sur micro et ont été opérationnels sur Vax.

Après le portage de l'application sur machine cible, un certain laps de temps est accordé au client avant la réception finale (recettage).

APPLICATIONS

Deux mois d'information et de recueil des applications potentielles sont au départ d'une liste d'une soixantaine de sujets porteurs d'intérêt pour la Lyonnaise des Eaux. Parmi ceux-là, certains sont plutôt des automatismes complexes. Les autres sont véritablement des outils intégrant une connaissance propre à la société.

En ce qui concerne les automatismes complexes, il s'agit surtout de prototyper par des méthodes de simulation une application qui est par la suite portée sur des machines et langages plus industriels (micro-ordinateur, langage Pascal, etc...).

Deux applications développées au L.A.A.C. vont être maintenant présentées. La première : "clarif", qui doit être un outil d'aide à la conception intégrant des connaissances expertes, la deuxième : "forages" qui est un exemple d'automatisme plus intelligent qui est développé de la manière déjà décrite.

Application "Clarif" (Sobral, R.)

La filiale Degrémont de la Lyonnaise est spécialisée dans la conception des chaînes de traitement d'eau. L'expertise nécessaire à la préparation d'une proposition technique réside chez de nombreux experts (ingénieurs de projets, ingénieurs de recherche, ingénieurs commerciaux). La mise à la disposition des différentes connaissances (par exemple : nouveaux appareils dont les conditions de fonctionnement sont connues des ingénieurs de recherche) serait un gain dans la productivité ainsi que dans la cohérence de la politique de la société.

Néanmoins la conception d'une filière complète n'est pas une mince affaire et des outils capables d'intégrer le problème complet sont plus un axe de recherche qu'un seul projet. "Clarif" doit être une esquisse du projet global (conception d'une filière de traitement). Il nous faut donc non seulement travailler la partie connaissance mais aussi l'ergonomie du système de façon à concevoir un véritable outil d'aide à la conception.

Le projet

La clarification est la première étape de traitement dans le processus de production d'eau quelle que soit la destination de celle-ci : consommation ou utilisation industrielle. Le but de la clarification est d'enlever à l'eau divers éléments indésirables tels que :

- brindilles, branches et feuilles,
- algues,
- sables, argiles et limons,
- matières en suspension,
- animalcules,
- colloïdes,
- couleur.

Le problème posé par la conception d'une clarification dans une usine de production d'eau est ardu du fait de :

- la variété des types d'eau à traiter (eaux d'origines diverses),
- la multitude des éléments à évacuer,
- la disparité des caractéristiques de ceux-ci (taille, sensibilité à un traitement, nature et forme),
- le nombre des opérations à effectuer,
- la quantité des appareils permettant de les réaliser,
- les compatibilités des opérations entre elles,
- les compatibilités des appareils entre eux,
- les desiderata du client,
- la législation,
- le site d'implantation (place disponible, structure du sol, climat, etc)
- l'exploitation envisagée,
- l'installation (neuve ou simple extension),
- la concurrence,
- les coûts.

Il est à noter que les liaisons avec le reste de la chaîne de conceptions apparaissent, par exemple, l'impossibilité d'utiliser un certain traitement après un autre. Ces types de contraintes sont pris en compte aujourd'hui en vue d'une intégration future.

Dès les premiers entretiens avec les experts en clarification, des maquettes ont été réalisées. Celles-ci avaient essentiellement pour but de faciliter l'acquisition des connaissances. En effet, un entretien est beaucoup plus productif lorsque l'expert doit réagir sur quelque chose de concret. De plus cela permet d'avoir une vision claire de l'évolution du projet. Ces maquettes successives qui ont été au nombre de huit se sont avérées être des impasses techniques. Elles ont néanmoins permis de tester différents moyens d'envisager le problème et de retenir les solutions les plus satisfaisantes. Ainsi dans un premier temps, l'arbre de choix des différentes techniques de clarification était modélisé aux moyens des viewpoints de ART. Il s'est avéré par la suite que la programmation objet était un support de représentation beaucoup plus performant. L'importance du maquettage rapide (possible grâce aux outils tels que ART) a aussi été démontré dans le processus de développement.

Implémentation choisie

En fait, il s'agit de la description du modèle de raisonnement choisi et de la définition des fonctionnalités du système notamment, le contrôle et les interfaces.

Modèle de raisonnement

Le réseau de schémas (les objets en ART) contient deux types d'informations :

- la décomposition du problème de la clarification en sous-problèmes, il s'agit d'une description statique de la clarification.

- la marche à suivre pour résoudre le problème.

En effet, ce réseau de schémas n'indique pas simplement quels sous-problèmes il faut résoudre, il donne une priorité à certains problèmes par rapport à d'autres. Ce réseau de schémas contient en fait les informations permettant de contrôler l'exécution de la tâche de conception de la clarification.

Les paquets de règles expertes contiennent l'expertise pour résoudre un problème bien précis, par exemple, déterminer quelle taille de sable utiliser dans un type de filtre donné ou bien choisir parmi deux appareils pratiquement équivalents. Ces paquets de règles qui contiennent une expertise très limitée mais très précise sont liés aux schémas du réseau présenté précédemment.

Le moteur d'exploitation du réseau de schémas permet d'utiliser l'expertise contenue dans les paquets de règles suivant l'information de contrôle qui réside dans le réseau de schémas. Il constitue le noyau du système de résolution du problème de la clarification. Ce noyau sera mis au point une fois pour toute et ne devra pas être modifié.

Interface et ergonomie

Du fait de la disparité de compétences des utilisateurs éventuels du système, il s'est avéré nécessaire de réaliser une interface avec l'utilisateur relativement élaborée capable de s'adapter. Par adaptabilité à l'utilisateur, il est signifié que le système doit pouvoir :

- laisser l'utilisateur libre de traiter les parties du problème qu'il sait et veut résoudre,

- reprendre la main quand l'utilisateur le demande et prolonger le travail de ce dernier en prenant en compte les résultats produits,

- s'apercevoir qu'il lui est difficile, étant donné les informations à sa disposition et l'état de résolution du problème, de traiter seul une partie de celui-ci,

- soumettre à l'utilisateur les choix ou alternatives qu'il serait coûteux d'explorer.

En bref, le système prévu ne doit pas se comporter comme une boite noire qui fournit un résultat mais doit être un système d'aide à la conception interactif.

D'autres fonctionnalités ont été prévues telles qu'une documentation en ligne, une explication des résultats obtenus, un archivage des sessions effectuées avec enrichissement des principaux types d'eau répertoriés, la possibilité de revisualiser une séance et de la reprendre en un point quelconque (Fig. 1.).

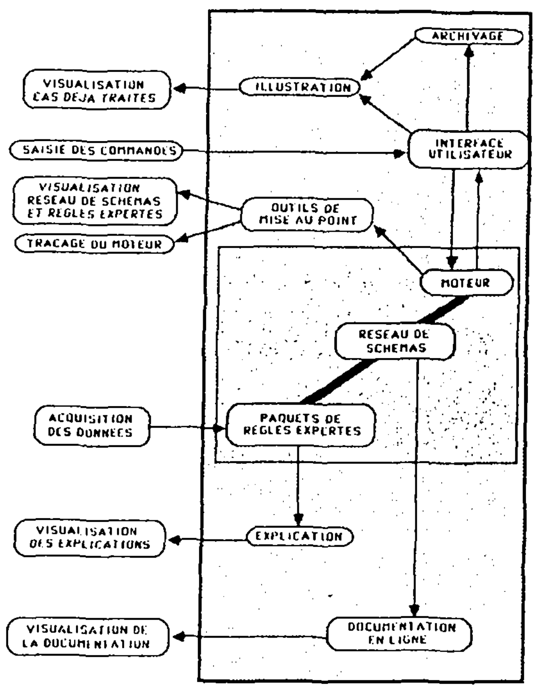

Fig. 1. Structure de l'application "Clarif"

Délais d'implémentation

Le système en cours de développement est en phase fin de maquettage et on donne ici une idée de l'effort consacré jusqu'à présent ainsi que la durée du beta test :

- ingénieur chef de projet et ingénieur conseil technique : 30 jours
- ingénieur développeur : 6 mois
- expert du domaine : 15 jours

La phase de beta test sera de quatre mois.

Suite du projet

Des réflexions sont menées pour le développement des interfaces propres aux développements concernant le reste de la chaîne de traitement. On entend pouvoir utiliser la même architecture pour toute la chaîne si elle est validée par les utilisateurs.

Application "Forages" (Fontaine, P.)

Cette application est d'une autre nature. Il s'agissait d'améliorer l'automatisation de l'usine de Vernouillet en ajoutant des contraintes du type qualité d'eau. On se trouve face à une application qui serait facilement programmable si l'on savait exactement ce qu'il était attendu du système. Il s'agissait donc surtout d'acquérir par des techniques de maquettage et simulation le comportement voulu de l'automatisme.

Les langages de programmation tels que règles de production et objets pour décrire les éléments en jeu, ainsi que la possibilité de faire des interfaces graphiques (animant la simulation à travers lesquels on peut agir sur les paramètres de cette simulation) ont permis un développement très rapide de cette application. On donne par la suite une description du projet.

Le projet

L'objectif de ce projet est la réalisation d'un système de gestion automatique des forages sur l'usine d'eau de Vernouillet. Le rôle de ce système sera d'améliorer le fonctionnement de l'automate actuel en échangeant des informations avec celui-ci. Afin de dégager les principales améliorations apportées par ce système, il est nécessaire de donner une description sommaire du fonctionnement actuel de l'usine.

Le site

Le site de Vernouillet est composé de :

- deux réservoirs qui approvisionnent la ville,
- une pompe pour chaque réservoir, le démarrage de ces pompes est effectué par l'automate en fonction de la hauteur d'eau des réservoirs,
- une bâche qui sert de réservoir tampon entre l'usine et les réservoirs,
- l'usine d'eau elle-même (traitement par nitrificateurs biologiques),
- les sept forages (dont six disponibles), le démarrage de ces forages est fonction de la hauteur d'eau de la bâche et des débits et des flux d'ammmoniaque de ces mêmes forages.

Actuellement le problème du choix des forages à démarrer est résolu par un automate qui choisit, parmi dix combinaisons pré-programmées, celle fournissant le débit le plus proche de celui réclamé par la bâche. Cette solution est acceptable du point de vue exploitation, dans la mesure où la contrainte d'approvisionnement en eau est respectée. Ses principales faiblesses se résument en deux points :

- Cette solution nécessite l'intervention régulière de l'ingénieur d'exploitation, pour modification des paramètres enregistrés dans l'automate.

- La contrainte qualité de l'eau n'est pas toujours respectée.

- Le rôle du système expert en cours d'élaboration est d'améliorer le fonctionnement de l'usine sur ces deux points, grâce à la prise en compte des critères suivants :

- choix parmi 57 combinaisons de forages,
- intégration des critères de qualité de manière plus restrictive, en tenant compte des résultats d'exploitation journaliers.

La gestion du démarrage des forages continuera a être effectuée par l'automate. Il sera chargé de fournir au système expert les paramètres nécessaires à son fonctionnement.

La simulation

Le module de simulation, développé pour tester les développements, et définir proprement ce que le système doit faire, prend en compte les paramètres suivants :

- le niveau d'eau dans les réservoirs et dans la bâche,
- les différents seuils de démarrage des pompes et des forages,
- l'évolution de la consommation durant la journée,
- les périodes de l'année,
- les caractéristiques des pompes et des forages (état, débit, flux d'ammoniaque),
- les contraintes de pointe EDF.

Le résultat obtenu est une simulation suffisamment correcte du fonctionnement de l'automate pour permettre la réalisation du système expert de choix des forages. Des prochaines améliorations seront apportées à cette maquette. En particulier :

- affinage des valeurs de consommation,
- prise en compte de l'inertie de l'usine.

Le système

Les critères de fonctionnement du système ont été obtenus en confrontant l'expert (ingénieur d'exploitation) avec les résultats obtenus par la simulation. Parmi ceux-ci, on peut citer :

- Recherche de la minimisation de la variation de flux entre deux journées. Par exemple : si le débit des forages est de 0 m3 pendant plus de six heures alors il faut remettre en cause les niveaux de la bâche.

- Minimisation du nombre de changements d'états des forages (une combinaison peut être meilleure car le nombre de changement d'états des forages est moindre).

- Mise en marche des forages ayant le plus d'ammoniaque à l'approche de l'été.

A partir de ces considérations, une architecture de système a été choisie et est présentée d'une manière schématique sur la figure 2.

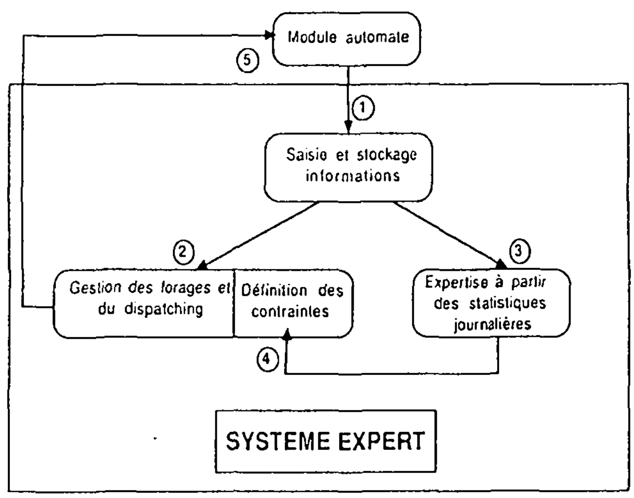

Fig. 2. Représentation schématique du système expert "Forages"

Le système est composé de trois modules :

- Un module chargé de la saisie et du stockage des informations en provenance de l'automate.

- Un module de gestion des forages, qui, à partir des règles d'expertise et de la définition des contraintes, fournit à l'automate la meilleure combinaison de forages à mettre en marche.

- Un module de redéfinition des contraintes, qui, à partir des statistiques journalières et des règles d'expertise, redéfinit les contraintes de fonctionnement de l'usine.

Implémentation opérationnelle

Il est à noter que la maquette développée sur ART est en train d'être portée sur micro-ordinateur et dans des langages plus standards tels que le Pascal, qui permettent une meilleure gestion de la mémoire.

Délais d'implémantation

Les délais approximatifs du développement sont les suivants :

Simulation : - ingénieur conseil 1 jour
- ingénieur développeur 15 jours
- expert (ingénieur d'exploitation) 2 jours

Recueil d'expertise : - ingénieur développeur 20 jours
- expert (ingénieur d'exploitation) 4 jours

Portage sur micro-ordinateur : - élève ingénieur 30 jours

- ingénieur développeur 5 jours
- ingénieur automaticien 2 jours

Le système "forages" est la première application développée par le L.A.A.C. dans le domaine de la conduite de process temps réel. L'expérience ainsi acquise dans ce domaine doit permettre dans le futur de passer à des applications complexes liées à la distribution d'eau telles que la gestion des réseaux.

En outre, l'application elle-même devrait être transposable à d'autres usines de production d'eau à partir d'un champ captant (Aubergenville, Le Pecq, etc...).

CONCLUSIONS ET PERSPECTIVES

Les enjeux auxquels les distributeurs d'eau devront répondre dans les années futures se résument à deux points principaux (Fiessinger, F.) :

- le respect des normes de qualité de plus en plus sévères tant au niveau des traitements sur les stations que de la stabilité de l'eau tout au long du réseau de distribution ;

- des gains de productivité dans tous les métiers touchant au domaine de l'eau (conception et construction de stations, production et distribution d'eau).

La réalisation de ces objectifs suppose la mise en oeuvre de techniques informatiques complexes permettant notamment l'interprétation de données en fonction d'un contexte (problèmes de goûts et odeurs), la prise en compte d'informations approximatives, incertaines ou manquantes (maintenance des réseaux de distribution), l'intégration de stratégies locales, multiples ou changeantes (conception de la partie clarification d'une filière) (Hayes-Roth, F.). Les techniques d'intelligence artificielle et, en particulier, les Systèmes Experts semblent des outils adaptés pour aborder ces types de problèmes.

Ainsi, la résolution des problèmes de goûts et odeurs sur des réseaux de distribution fait appel à l'exploitation de données qualitatives (chromatogrammes en phase gazeuse, spectres de masse, profils de flaveurs,...) par des spécialistes d'analyse et de traitement des eaux avertis. Leurs raisonnements, parfois mal formalisés, ne peuvent être réellement pris en compte que par un outil aussi souple qu'un Système Expert.

Le pilotage de systèmes de traitement ou de distribution de l'eau (osmoseur, exploitation des réseaux) peut avantageusement être abordé à partir des techniques de planification sous contraintes.

La détection des pannes et incidents (clarification, réseau de distribution) fait appel à des techniques de reconnaissance de configurations d'indices n'ayant de significations que considérés comme faisant partie d'un ensemble.

La récupération de l'expertise est généralement le "goulot d'étranglement" pour la réalisation de tels systèmes. En effet, cette acquisition de la connaissance est souvent longue, les experts sont peu disponibles et, parfois, peu aptes à communiquer formellement leur savoir.

L'acquisition automatique des connaissances (interrogation automatique de l'expert, induction de règles à partir de documents papier ou de bases de données,...) (Boose, J.H.) et la capacité à composer avec des situations nouvelles (apprentissage) (Quinlan, J.R.) sont des voies de recherche prometteuses pour l'avenir.

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EXPERT SYSTEMS FOR CHEMICAL LABORATORIES

Author: J. Groennou

The Netherlands Waterworks Testing and Research Institute KIWA Ltd,
P.O. Box 1072, 3430 BB Nieuwegein, The Netherlands

ABSTRACT

Artificial Intelligence (AI) is concerned with solving problems in a similar way as human beings would do. One of the subareas of AI, expert systems, consists of computerprograms that use knowledge of experts and an inference mechanism to solve problems that require significant human expertise. Expertise is a combination of knowledge (facts and heuristics) and capability of solving difficult problems. Each of the basic components of an expert system (knowledge base, knowledge acquisition subsystem, inference mechanism and user interface) will be discussed and attention will be paid to the strength and weakness of expert systems. Expert systems have a number of benefits but before starting to develop expert systems it is important to test the problems on criteria. This is shown, as an example, for some subjects of interest for a chemical laboratory. Developing an expert system is a project that can be subdivided into phases. Each phase requires a certain time and should be monitored. A selection of available expert systems is given as well as the expected development of the expert system market. The way in which they will be used depends to a large extent on the type of company. For laboratories it is of great importance to start obtaining exerience with small systems. The routine work of laboratories will in 2000 mainly be done by robots, expert systems and computers. However, the need for high classified employees for research work will increase.

KEYWORDS

Expert system; expertise; knowledge; knowledge acquisition; inference mechanism; user interface; tools.

INTRODUCTION

Artificial intelligence (AI) is concerned with developing computer programs that are able to solve problems and produce results in a similar way as human beings would normally do. The field of AI can be subdivided into a number of subareas, such as:
- natural language processing
- robotics
- expert systems

This paper will be concerned with the subarea of expert systems. An expert system can be defined as:
An intelligent computerprogram that uses the knowledge of an expert and an inference mechanism to solve problems that are difficult enough to require significant human expertise for their solution.

NATURE OF EXPERTISE

In the given definition of expert systems the conception expertise is included which requires a further explanation. If people are asked to describe what an expert is they might answer that it is an individual who:
- knows a lot about a very specific (small) area
- is able to solve problems that other individuals cannot solve as efficiently or effectively.

The first item says something about the knowledge of the expert. There are two main ways to compile knowledge:
- by learning from school and books
- by learning from experience and from other people

Since everyone has to go to school from the age of 5 until they finish their education everyone learns from school and books. In this way individuals compile general theories. This kind of knowledge is referred to as deep knowledge (facts).
At the moment people leave school they have hardly practised what they have learned (they only have theoretical- knowledge). When they start working and apply what they learned they start gaining experience. They also gain experience by talking with their mentor and with people who work longer in this field. This kind of knowledge is referred to as surface knowledge (heuristics).

The second item focuses the attention on the way he uses his knowledge, it says something about the way he performs. The combination of both items says something about the expertise. The graphs in figure 1 visualise the domains in which there is expertise within a company (Harmon and King, 1985).

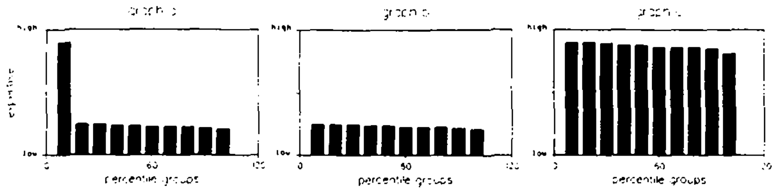

Fig. 1. Domains in which there is expertise within a group

Graph A shows the case where the level of expertise of a small group is very high and the level of expertise of the rest is low. This situation exists, for instance in chemical laboratories, where only few individuals have expertise in the area of mass-spectrometry whereas the rest has hardly or no expertise at all in this area.
Graph B shows the case where none of the individuals has (very) much expertise. This situation is found, for instance in chemical laboratories, on the moment they start with a new technique such as laboratory information management systems (LIMS).
Graph C shows the case where almost all the individuals have (very) much expertise. This situation is found, for instance in chemical laboratories, if they are specialized in a very narrow task.

COMPONENTS OF AN EXPERT SYSTEM

The architecture of an expert system is shown in figure 2. The system has the following basic components:
- knowledge base
- knowledge acquisition subsystem
- inference mechanism
- user interface

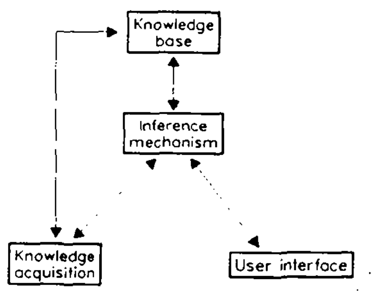

Fig. 2. The architecture of an expert system

knowledge base

Human experts solve problems by using domain-specific facts and heuristics. There are several ways to represent this knowledge in a expert system, such as:
- semantic networks
- rules
- frames

Semantic networks consist of a collection of nodes and links. The nodes are used to represent physical objects like mass-spectra, conceptual entities like numbers or descriptors that give additional information. The links are used to relate objects and descriptors (is-a or has-a link).

Rules are used to represent relations and they consist of two parts, a premise and a conclusion. The premise consists of an 'if' clause and the conclusion consists of a 'then' clause. The conclusion of the 'then' clause will be accepted if the premise of the 'if' clause is true, otherwise it might be rejected. An example of a rule is:

Premise   if   the car has no gasoline
Conclusion then the car does not start

A frame is a description of an object that contains slots for all the information associated with the object. A slot can contain default values, pointers to others frames, procedures or rules to obtain other values. Frames are more powerful to represent knowledge then semantic networks or rules, but they are also more difficult to develop.

Knowledge acquisition

An expert system without knowledge cannot work. Knowledge acquisition is the component of an expert system that is concerned with acquiring and analysing knowledge. The most import tasks are:

- to acquire the knowledge of an expert
  The knowledge of an expert consists of facts and rules (of thumb). It is the task of the knowledge engineer to acquire this knowledge, especially the heuristics. This can be done by means of interviews or by learning from examples (let the expert solve problems and extract the characteristics/features he uses).
  To do this job it is necessary that the knowledge engineer has good contactual qualities, that he can express himself well and that he is able to listen carefully.

- to implement the available knowledge
  Once the knowledge of an expert is available it has to be put into the computer. To do this job it is necessary that the knowledge engineer has knowledge of computersystems and tools.

Inference mechanism

The inference mechanism is the component of an expert system that makes it able to draw conclusions and to derive new knowledge from already available knowledge. The inference mechanism makes, in most cases, use of the following two techniques to look for possible solutions within the knowledge base:
- forward chaining
- backward chaining

The forward chaining technique is facts oriented. It makes use of available knowledge to suggest goals. This technique is used when there are lots of facts but it is not clear what to do first.
The backward chaining technique is goal oriented. It starts from a possible goal and uses facts to prove that it is the wright one.
In most cases a combination of both techniques is used. Starting from available facts a possible conclusion is drawn. New data are then collected and used to prove that the conclusion is true. In most cases it will be an iterative process and switches will be made between forward and backward chaining.

User interface

The user interface provides the communication between the expert system and the user of the system. User interface features include among others the passing of results, explanation facilities and provision of interaction between expert system and user.
To pass results is of course a selfevident facility because the system has to show the results.
The function of the explanation facilities is to explain the user why a certain conclusion is drawn and why certain questions are asked. It allows the user to follow the logic of the system. This feature is very important and one of the most essential parts of an expert system.
Provision of interaction between the expert system and the user means that the user as well as the expert system can ask and answer questions. Since the user, in most cases, will not be a computer specialist it is necessary that the communication takes place in an user friendly way.

PERFORMANCE OF EXPERT SYSTEMS

Strength of expert systems

Expert systems are computer programs that make use of the knowledge of experts (facts, experience and rules of thumbs). This makes it possible to reuse the knowledge as often as required and it is also possible to check the knowledge on consistency and completeness.
In most cases expert systems make a choice between a number of competing hypothesis.
Expert systems are able to explain how they make choices and recommendations or assign weights to alternatives.
The capacity of expert systems to solve difficult problems depends on the quality and amount of acquired knowledge (by the knowledge engineer) and the inference mechanism that is used.
Good expert systems can solve difficult problems, within a narrow domain, as well as or better than human experts.

Weakness of expert systems

Expert systems cannot reason from axioms and general knowledge. They can only use knowledge that is available in the knowledge base (they cannot learn) and they cannot transplant knowledge from one specific domain to another.
Since experts sometimes contradict each other it is desirable to use the knowledge of only one expert.
Knowledge acquisition takes a lot of time and is very expensive. The performance of expert systems gets worse when the problem extends beyond the narrow domain they were developed. At this moment the available expert systems are not able to solve complex problems.
The speed with which expert systems solve problems at present is too low, but this will probably change in the near future.

BENEFITS OF EXPERT SYSTEMS

Reasons for using expert systems are:

- to discharge experts
  As mentioned earlier, every company has only few experts. This implies that the expert is very busy and it is a pity if he has to waste his time on routine jobs. In the case a company has an expert system for routine jobs the expert will spend his time in a more valuable way (for example on research and development).

- to have knowledge/expertise available
  This is of interest in the case an expert is not available because he is on holiday or because he left the company. It is however necessary that other people in the company are able to use the expert system.
  Expert systems may also be valuable for developing countries that for instance have the technique/-apparatus but do not have an expert. For them the same applies as for companies: they must have people who are able to use the system.

- to formalise knowledge
  The knowledge of experts is in most cases not formalised. One of the reasons is that it is difficult to write down the heuristics. Another reason is that they are too busy to do so. One of the great advantages of developing expert systems is that the knowledge of the expert will be embodied.

- to educate and to train people
  If an expert system is available it can be used for education and training of people. Education means that people will be taught to think in abstract terms. Training means that people are learned to carry out particular procedures or to perform a particular taught job.

CHOOSING THE PROBLEM

The most important step when choosing a problem for which an expert system has to be developed is to pick-up the right problem. To do so it is necessary to have the disposal of good criteria. A number of this criteria are:

1 make sure the problem can be solved by human experts
  If people cannot solve the problem it is difficult or even impossible to develop an expert system because, for example, the knowledge base will be empty.

2 make sure there is an expert available who will corporate
  To develop expert systems it is desirable, although not necessary, that there is an expert available who wants to coorporate. The expert must have time and must be motivated to coorporate. It is not necessary because (part of) the knowledge can also be obtained from books. This however will be more difficult with the heuristics.

3 make sure the problem is clearly defined
  Expert systems are optimal for narrow tasks. It makes no sense to develop an expert system for the identification of any kind of parameters in drinking water. It will make sense however to identify parameters with the aid of mass-spectrometry.

4 choose problems for which it takes six to twelve months to develop expertise
  If the problem is too easy, people will not be impressed by the performance of the expert system. If the problem is too complicated it will take too much time to develop the expert system and people will become sceptical about the possibilities.
  Another aspect to consider here are the costs to develop expert systems. When it takes too much time to develop an expert system it will become too expensive.

5 avoid problems that require creativity
  Expert systems can be compared with cook books (recipe books). As mentioned earlier they cannot learn and are not able to transplant knowledge from one domain to another.

6 make sure users want it
  Expert systems must work in a way the users want it to work. If that is not the case nobody will use them. In the extreme case users do not want expert systems at all, they will fail.

7 avoid problems that are reduced to formulas
  It makes no sense to develop expert systems for problems that can be solved using 'brute force' and/or formulas.

SUBJECTS OF INTEREST

A number of applications, within chemical laboratories of drinking water companies, for which it will make sense to develop an expert system are:

- interpretation of spectra
- developing measurement strategies
- developing monitoring strategies
- developing laboratory information and management systems (LIMS)
- developing statistical analysis strategies
- interpretation of time series
- permeation of materials through pipes

TEST SUBJECTS TO CRITERIA

To decide whether it makes sense to develop expert systems for the cited subjects it is necessary to test them on the basis of the mentioned criteria. The results of the test for a certain chemical laboratory might be as shown in table 1. (In the table the numbers of the corresponding criteria are used instead of their description).

SUBJECT	NUMBER OF CRITERIA							
	1	2	3	4	5	6	7	TOTAL
INTERPRETATION OF SPECTRA	++	+	++	+	++	+	++	11
DEVELOPING MEASUREMENT STRATEGIES	++	+	+	-	+	-	++	5
DEVELOPING MONITORING STRATEGIES	++	+	+	-	+	-	++	5
DEVELOPING LIMS	++	--	+	-	-	-	++	0
DEVELOPING STATISTICAL ANALYSIS STRATEGIES	++	+	+	+	+	-	+	6
INTERPRETATION OF TIME SERIES	++	++	+	++	+	+	++	11
PERMEATION OF MATERIALS THROUGH PIPES	++	+	+	+	+	++	++	10

Tabel 1 Results of the test on basis of the mentioned criteria

On the base of these results a selection should be made between interpretation of spectra, time series analysis or permeation.

DEVELOPING AN EXPERT SYSTEM

Developing an expert system is something that cannot be done at once. The best way to do this is using a system development technique as is used for projects (and for information analysis). This means that one has to go through a number of phases which consist of activities. A possible choice is (Harmon and King, 1985)

phase 1 - selection of an appropriate problem
phase 2 - development of a prototype system
phase 3 - development of a complete expert system
phase 4 - validation of the expert system
phase 5 - integration of the system
phase 6 - maintenance of the system

Selection of an appropiate problem is the result of the test of subjects of interest to criteria.
The time needed for the different phases depends on the problem. It is, however, a fact that the third phase will take most of the time. The reason for this is that most of the work concerned with knowledge acquisition will be done here. To gain time it is advisable to make use of 'empty shells'. This can however, as mentioned earlier, only be done if the inference mechanism of the 'empty shell' fits the needs of the problem.

SYSTEMS DEVELOPED UNTIL NOW

Most of the available expert systems come from universities (the earlier ones) or from commercial firms (the later ones). A selection of the systems, with their field of application, is given below (Harmon and King, 1985).

DENDRAL	spectroscopic analysis of an unknown molecule
GENESIS	helps molecular genetics plan DNA experiments
MACSYMA	mathematical problem solver
XCON	helps configurate computersystems
DELTA/ CATS-1	helps locomotive maintenance personnel
DRILLING ADVISOR	assists oil rig supervisors to solve problems
HEARSAY	carry on conversation
MYCIN	helps physicians in the diagnosis and treatment of meningitis and bacteremia infections
PUFF	helps physicians in interpreting respiratory tests
INTERNIST/ CADUCEUS	medical diagnosis system

Most of the expert systems developed so far are build for problems that do not need a very high level of creativity such as diagnosis and training. Kleywegt (1987) gives a synopsis of artificial intelligence in chemistry.

EXPERT SYSTEMS IN THE FUTURE

So far attention was focused on what expert systems are, how they work, what their benefits are and how to choose subjects to start with.
Before going into how expert systems will be used in the future, it is necessary to say something about the type of companies that will use them and the expected development of the expert system market.

Types of companies that will use expert systems

The way in which expert systems will be used in the (near) future depends to a large extent on the position companies take with regard to the use of new techniques. Companies can, as to that, be divided into the following three types:
- cutting-edge companies
- advanced companies
- normal companies

Cutting-edge companies introduce new techniques at the moment they leave the universities. These companies spend a lot of time and money investigating the possibilities of commercialyzing these new techniques. Because it is not certain in advance that it will succeed they expose themselves to high risks. In the case of expert systems there are a lot of companies working hard on it.

Advanced companies apply new techniques only if it has been proved that they can be applied in practice. These companies want to use the new techniques as soon as possible but cannot afford to expose themselves to the high risks connected with the investigation in the research stage. They are only willing to spend time and money in the development stage.

Normal companies invest only in new techniques at the moment they have proved to work. These companies do not spend time and money in the research and development stage. They only spend money in buying ready-to-use systems.

Expected developmend of the market.

The expectation for the future is that the impact will come in two waves.
The first wave goes from now until say 1990. This wave will include small systems for specific problems and large, narrow systems.

Small systems are expert systems with 50 to 500 rules. Such systems are already available and can be developed using special artificial languages as LISP or PROLOG. They can also be developed by users on personal computers using special tools like "empty shells". An "empty shell" is an expert system from which the knowledge is taken off. There is however one restriction using "empty shells" and that is that the new problem has to use the same inference mechanism.
It is advisable to users to acquire knwoledge engineering techniques before starting to build expert systems.

Large, narrow systems are expert systems with 500 to 3000 rules. Such systems have to be runed on large computer systems (LISP-machines) and are able to use several problem solving strategies (consultation paradigmas). To build these systems it is necessary to have some knowledge of special artificial intelligence languages such as LISP or PROLOG. For this reason it is not recommended to users to build their own expert system. These type of expert systems are coming available at this moment.

The second wave will start in say 1990 and will include large, hybrid expert systems.

Large, hybrid systems have to be runed on large computer systems (LISP-machines) and are able to use several consultation paradigmas, inference strategies and knowledge representation. With these systems it is possible to build tools that can build other tools. With this kind of expert systems it will be possible to permit several knowledge bases to cooperate in analyzing a specific case. These systems will be difficult to build and it will be necessary to know a lot about knowledge engineering and about special artificial intelligence languages as INTERLISP.As mentioned before this type of systems will, at the earliest, be available in the 1990s.

Also in the 1990s a start will be made with building second generation expert systems. These systems will use besides heuristic knowledge also knowledge derived from special deep-models (for instance causal models that referes to the underlying physical principles). Second generation expert systems will, to solve problems, first use heuristic knowledge. If this fails they will resort to deep reasoning using knowledge derived from the deep-model. They will also be able to learn from experience. Their main use will lie in technical areas such as developing computerprograms, controling nuclear power stations and decision support systems.
At the same time (normal) computersystems also will become bigger and faster. This implies that search procedures will improve too, so that it may become possible to solve problems with so called "brut force" techniques instead of expert systems. The question is whether future computers will be fast enough to effectively tackle the combinatorial explosion connected to "brute force" techniques. The best solution might be to improve search procedures within expert systems and make LISP computers faster.

OBTAINING EXPERIENCE WITH EXPERT SYSTEMS

As stated in the preceding section the use of expert systems will principally depend on the type of company.

Chemical laboratories of drinking water companies may be classified as normal companies. For them there is no need to invest in research and/or development.

Chemical laboratories of the national research institutes of the drinking water companies (for instance the chemical laboratory of the Netherlands Waterworks' testing and research institute, KIWA Ltd) may be classified as advanced companies. For them it is important to spend time and money in developing expert systems and building know-how to be able to assist and/or give advise to the chemical laboratories of drinking water companies. The benefit for the laboratories of the drinking water companies is that the laboratories of the national research institutes can combine knowledge of chemistry and how laboratories work with their (new) obtained knowledge of expert systems.

It is however advisable that the laboratoris of the national research institutes and of the drinking water companies work together investigating the possibilities of expert systems. This means, in view of the development of the expert system market, that a start must be made with doing experiments with small expert systems. Hereby people will learn what expert systems are and what they can expect from them. Meanwhile the laboratories of the national institutes can begin to obtain understanding of the larger systems.

To start with obtaining experience with expert systems KIWA will start to develop some small systems. This will be done between now and 1990.
Subjects for which it makes sense to develop small expert systems are:
- interpretation of spectra
- interpretation of time series
- permeation of materials through pipes

If enough experience has been gained with building small systems the next step will be to build large systems. It is expected that this will be done in the 1990s. Subjects of interest might be:
- developing monitoring strategies
- developing measurement strategies
- developing laboratorium information and management systems

At this moment experience is being obtained with information analysis and data management systems. For the future it will be of great interest to obtain also experience with robots. The trias computing techniques, expert systems and robot technology will be essential for working on a high level within chemical laboratories.

CHEMICAL LABORATORIES IN 2000

In the 1990s the laboratories of drinking water companies will obtain experience with building and implementing expert systems.
From 2000 on daily work in the laboratories will be supported by expert systems. That means that there will be expert systems for the common functions mentioned earlier.

Management

Managers will use expert systems that assist them in reviewing and digesting the increasing stream of information necessary to make rational decisions. They will also make use of expert systems that provide them advice in specific areas such as accounting, finance, government regulations, legal aspects and public relations.

Operations

Expert systems will help to improve the productivity of the laboratories. That means that the overall coordination of analysis, interpretation, scheduling and management will be improved. Expert systems will also be used to design the experiments for planning at the level of laboratory organization and to (statistical) analyse the results. Measurement instruments will be provided with hardware (microprocessors) that contain expert systems with which it will be possible to optimize the adjustment of the instrument. It will also be possible to interpret, evaluate and report the results immediately and, if wished, give advise to the client.
Besides expert systems laboratories will be provided with robots that can help to reduce routine actions of the exployees to a minimum.
All this does not mean that the laboratory of the future will look like a deserted room. Expert systems reach solutions through which laboratory employees can concentrate on others tasks like improving existing techniques or developing techniques for new problems.

Support

Support services range from training and personnel services to computer services, maintenance services and even research and development services.
Expert systems will be available for training and to assist in performing daily jobs (job aid). Training will become very important because the level of the jobs will be much higher (the routine jobs are done by robots and expert systems) and because it will be necessary to retain expertise in routine jobs (in ase it must be done without the help of the available expert system).
Assisting in performing daily jobs will be done when accuracy is more important than speed, tasks are performed infrequently and tasks involve a complex decision making process (otherwise employees have to memorize the necessary actions).
Expert systems will be used to help data processing departments to tackle large, difficult problems. They will be useful in the field of information analysis and data base management systems.
Expert systems will be used to do the maintenance services. The system will ask appropiate questions so that the user can repair minor problems and the specialists can concentrate on major problems.

Office automation

Intelligent typewriters will be available that are able to type what the manager or employee speaks into a microphone.

Professional services

Professional advice will be supported by expert systems. Reports of professionals will no longer be typed reports but floppy disks containing the rules and assumptions used by them during the study.
The client will be able to review the rules and assumptions and, if desired, change some of them to consider alternatives.

CONCLUSION

In the laboratory of the future routine work will be done by expert systems, robots and computer systems. Some of the actions of the different mentioned components are given below.

Expert systems will among others:
- tell how, where and how often to sample
- control the instruments by tuning and calibrating them
- interpret and report the results
- give advice to the client

Robots will among others:
- mix the samples
- pass the samples to the instruments

Computer systems will among others:
- report the results
- control the information and management system

This does not mean that laboratories of the future will be empty buildings ocupied only by robots, expert systems and computers. The number of employees of laboratories will not change but they can do work of a higher level. In the future there will be a need for more complicated chemical analyses thechniques. There will also be a need to improve the present techniques. This means that the need for research will grow.

Since everything is going very fast it is recommended to start as soon as possible. It is a challenge for the drinking water laboratories that they have to grasp with both hands.

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SESSION 7

SEANCE 7

Chairman
Président Dr.-Ing. H. TESSENDORFF

- High Technology and the Water Profession : Conditions for Success in the Year 2000

  Les Technologies de pointe et le Métier de l'Eau : Les Conditions d'un succès en l'An 2000

  D. Caille

- Water Supply and Energy Consumption

  Approvisionnement en eau et consommation énergétique

  W. Würth

- Emerging US Water Technologies

  Technologies émergeantes de l'eau aux Etats- Unis

  K. J. Miller

Discussion

LES TECHNOLOGIES DE POINTE ET LE METIER DE L'EAU
LES CONDITIONS DE SUCCES EN L'AN 2000

par **Daniel CAILLE**
Professeur à l'ECOLE NATIONALE DES PONTS ET CHAUSSEES
Directeur d'ANJOU RECHERCHE - COMPAGNIE GENERALE DES EAUX
52, rue d'Anjou - 75008 PARIS (France)

RESUME

Après avoir passé en revue les principales mutations techniques qui se sont ou vont se manifester dans le métier de l'eau au cours des 10 prochaines années (instrumentation, automatisme, télégestion, CAO, biotechnologies, nouveaux matériaux, intelligence artificielle, robotique, etc...) l'auteur donne des exemples du mode d'apparition et de l'évolution de ces nouvelles technologies tant en France que dans le monde où le groupe GENERALE DES EAUX est présent.

Il démontre ensuite que si l'on cherche à évaluer les éléments de succès d'une technologie en cours de développement, il convient de bien prendre en compte certaines caractéristiques du métier de l'eau (diversité des situations locales, variabilité de la matière première, lourdeur des investissements, etc...). Quelques étapes du chemin de l'innovation sont décrites (assimilation du concept technique, organisation des compétences, définition des objectifs, expérimentation pilote, etc...), les éléments moteurs et les erreurs à éviter sont évoqués.

Il apparait que le véritable critère discriminant d'une entreprise de service qui gagne dans le métier de l'eau est le degré d'ouverture à l'innovation que manifestent les responsables locaux d'un service d'eau.

MOTS CLES

An 2000 - Biotechnologies - C A O - Ecole Française de l'Eau - Formation - Goûts et Odeurs - Informatique - Innovation - Management - Matériaux composites - Robotique - Systèmes Experts - Ultrafiltration.

I - LES MUTATIONS TECHNIQUES EN COURS

Au cours des dix années passées et au cours des dix années à venir, des mutations techniques importantes se sont ou vont se manifester dans le métier de l'eau.

Au delà de quelques découvertes et innovations ponctuelles, des grandes lames de fond technologiques apparaissent dont on peut citer quelques exemples :

. L'**instrumentation**, les **automatismes** et la **télégestion**. Ces trois domaines connexes se sont considérablement développés notamment depuis 1980 pour atteindre des objectifs multiples : augmentation de la productivité mais aussi renforcement de la qualité du service, de la sécurité qui y est attachée et l'amélioration des conditions de travail. Par exemple, le groupe GENERALE DES EAUX comptait fin 86, sur le territoire français, 120 postes centraux informatiques installés et 2 230 ouvrages télécontrôlés dans le domaine de la distribution de l'eau (Fig. 1).

. En 10 ans la C A O est en train de faire évoluer lentement les techniques de **conception** des ouvrages. En effet, l'utilisation de plus en plus générale des outils de dessin ou de conception assistée par ordinateur permettent maintenant non seulement de réduire le coût des études préliminaires (conception d'ensemble) ou des études de réalisation (calcul des structures) mais surtout d'introduire une plus grande souplesse favorable à l'optimisation des ouvrages eux-mêmes (Fig. 2). Nous disposons aujourd'hui d'une gamme complète avec à la fois de petits progiciels informatiques fonctionnant sur micro-ordinateurs permettant de traiter de nombreuses configurations à la portée de tous les services d'eau et des outils de conception tridimensionnels plus lourds réservés à l'étude et la réalisation de cas plus complexes (ouvrages d'art par exemple).

. La **biotechnologie** a maintenant retrouvé la place qui était la sienne il y a 20 ans (Fig 3). Les conditions d'élimination de l'ammoniaque par suppression de la pré-chloration, l'élimination du fer et ou du manganèse par voie biologique sont maintenant bien maitrisées même dans le cas d'une installation déjà existante. De plus la dénitrification biologique des eaux potables a souvent été évoquée (Eragny 1983). On apprécie maintenant outre la qualité de l'eau produite et l'économie d'exploitation, la stabilité du processus biologique et sa rapidité.

. Dans le domaine des canalisations, plus timidement quoique de façon tout aussi irrémédiable, après les matériaux composites traditionnels (ex. béton avec âme-tôle des tuyaux BONNA), après la **préfabrication** de plus en plus poussée auquelle on assiste dans le génie civil appliqué aux ouvrages d'eau, les **nouveaux matériaux** sont apparus : PVC et polyéthylène haute densité pour les petits diamètres, mais aussi matériaux composites avec le Septub (Fig. 4) (PVC, fibre de verre, résine) de la Société SEPEREF, qui est d'ores et déjà compétitif jusqu'à des diamètres de 400 mm.

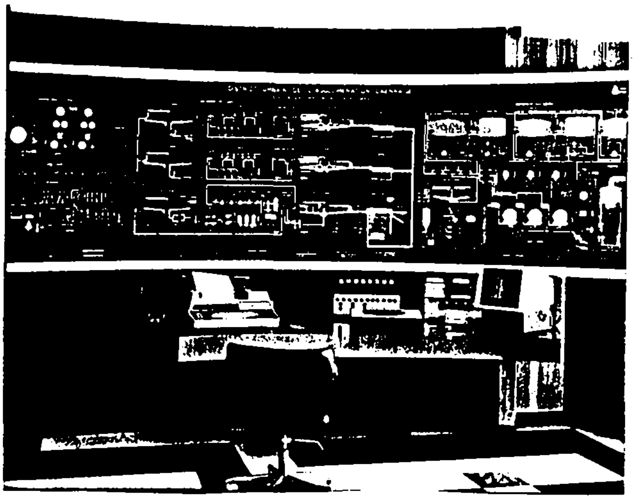

Fig. 1. L'instrumentation, les automatismes et la télégestion permettent non seulement d'augmenter la productivité mais aussi la qualité du service, la sécurité qui y est attaché et l'amélioration des conditions de travail (document OTV)

Fig. 2. La CAO et la DAO permettent non seulement de réduire le coût des études mais surtout d'introduire une plus grande souplesse favorable à l'optimisation des ouvrages (document CAMPENON BERNARD)

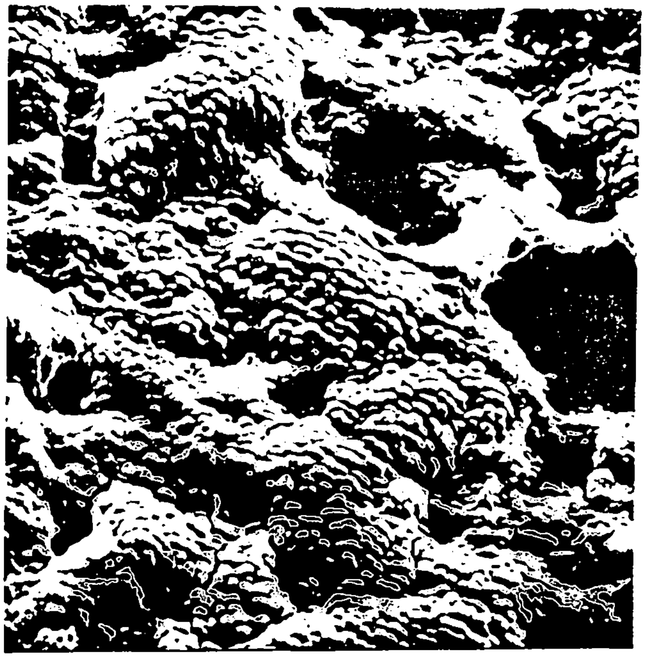

Fig. 3. Une large part des biotechnologies repose sur l'usage des microorganismes : cette vue au microscope électronique montre l'étonnante concentration en cellules vivantes que l'on peut obtenir (document ANJOU RECHERCHE)

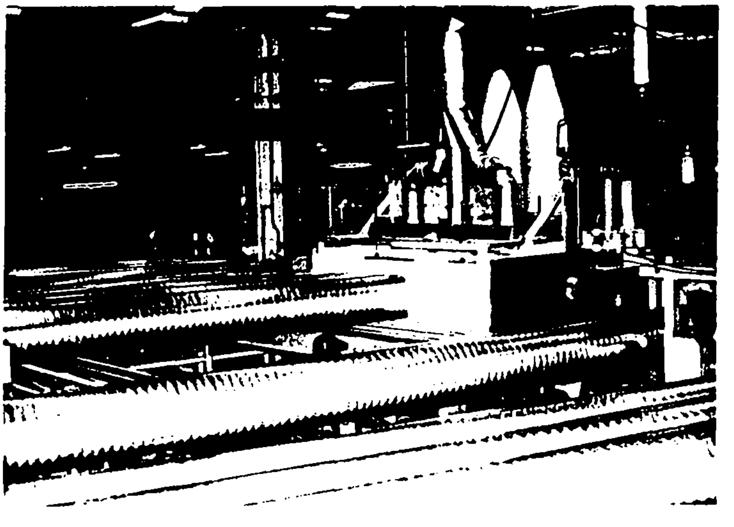

Fig. 4. Des progrès décisifs ont été réalisés ces dernières années dans la conception et la fabrication des matériaux composites. On voit ici la ligne de fabrication du tuyau composite SEPEREF qui a industrialisé ces techniques pour la production en grande série de canalisations de transport d'eau sous pression (document SEPEREF)

. Plus récemment les **systèmes experts** sont apparus comme un outil privilégié d'aide à l'exploitation (lavage des filtres, gestion centralisée de l'hydraulique du réseau, gestion complète d'une usine de traitement). Aussi par exemple en 1986 la C E O filiale de la GENERALE DES EAUX a mis en service le système OPHELIE à l'usine de traitement d'eau potable d'Itteville.

. Dans un avenir proche la **robotique** et la **télémanipulation** (Fig 5) à distance déboucheront certainement dans les deux domaines de la pose et de l'entretien des canalisations... au terme d'une mécanisation de plus en plus poussée de ce métier. Par exemple la pelle hydraulique multi-outils permettant de creuser et d'effectuer les fonds de fouilles et de poser ces canalisations dans la tranchée ainsi que l'outil d'inspection et de réhabilitation autonome sont probablement pour demain. C'est donc à la fois l'amélioration des conditions de travail et de la productivité qui seront rendues possibles et qui nécessiteront là aussi une nouvelle organisation du travail.

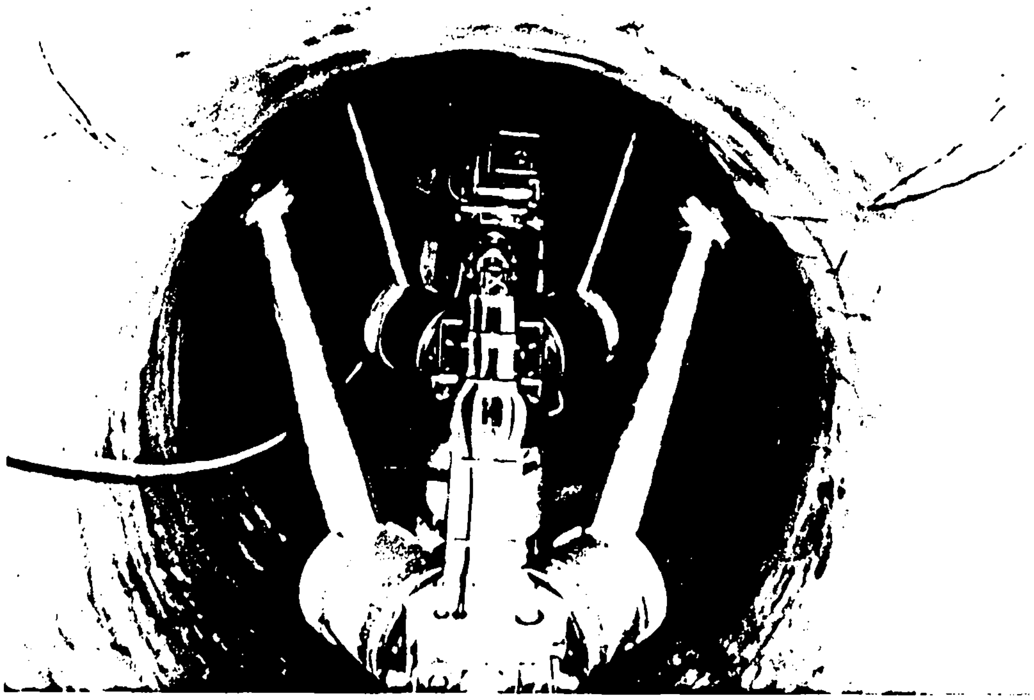

Fig. 5. La robotique et la télémanipulation permettront à la fois l'amélioration des conditions de travail et de la productivité (document CEA)

II - L'EVOLUTION DES TECHNIQUES DE DEMAIN

On pourrait bien sûr multiplier les exemples. Ce n'est pas le plus intéressant. En effet, quand on examine ces techniques de demain et leur devenir, la question centrale est d'être capable de mesurer périodiquement les **chances de succès d'une technique** et les **mesures** d'accompagnement à entreprendre : présentation du produit, standardisation, formation du personnel, réflexion sur l'organisation du travail, etc...

Là aussi donnons quelques exemples des enjeux de demain :

- Pourquoi les techniques de l'intelligence artificielle en plein développement ont une chance réelle de trouver dans le domaine de l'aide à l'exploitation des ouvrages de production et de distribution, un champ d'application que n'a pas pu trouver la modélisation physique, statistique, c'est-à-dire la représentation numérique du phénomène?

- Est-ce que la technologie de filtration sur membrane pourra connaitre une application raisonnablement large dans le domaine du traitement de l'eau potable ?

- Est-ce que les acquis les plus fondamentaux de la biotechnologie (sélection des souches, génie génétique, enzymes fixés) pourront s'appliquer dans un milieu aussi dilué et variable que l'eau brute d'une usine de traitement des eaux ?

- Est-ce que l'outil *télématique (messagerie vidéotex, minitel) pourra trouver sa place dans un service de gestion* des eaux, avec une structure décentralisée, ne serait-ce que pour faciliter la communication d'entreprise, problème majeur de ce métier ?

- Est-ce qu'au delà des applications particulières de l'informatisation d'un service d'eau, les systèmes de gestion de base de données pourront jouer le rôle de plaque tournante entre ces applications malgré la standardisation encore bien insuffisante des produits informatiques ?

- Est-ce que les avances considérables effectuées dans l'analyse des saveurs et des odeurs de l'eau pourront déboucher sur l'élaboration d'un "nez artificiel" combinant l'acquis et la sensibilité irremplaçable du nez humain avec des appareils comme les spectographes de masse et les chromatographes en phase gazeuse ou liquide ? (Fig. 6)

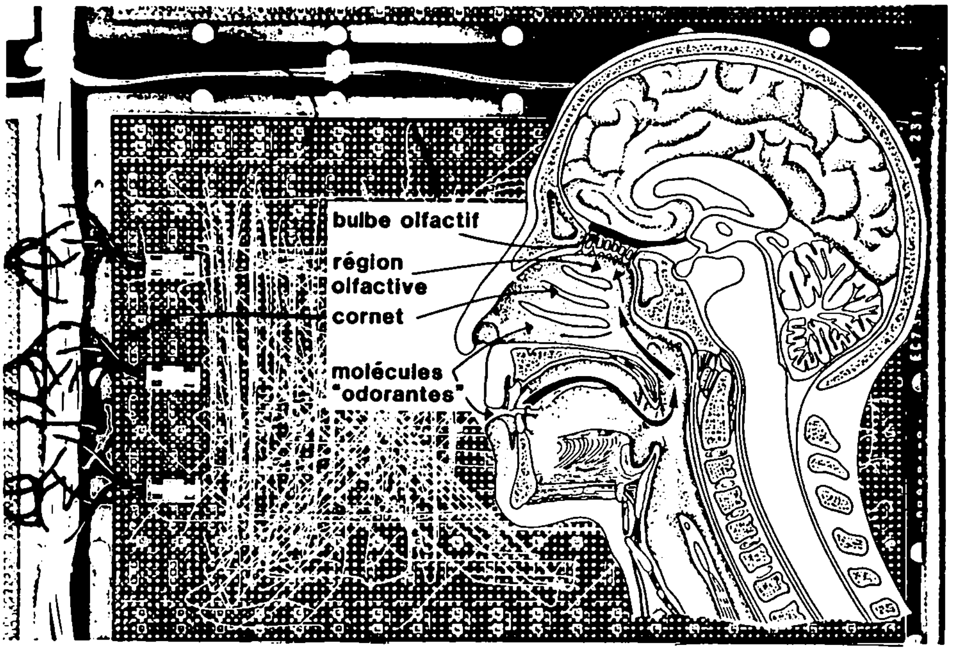

Fig. 6. Les avances considérables effectuées dans l'analyse des goûts et des odeurs de l'eau pourront-elles déboucher sur l'élaboration d'un "nez artificiel" combinant l'acquis et la sensibilité irremplaçable du nez humain, avec des appareils comme les spectrographes de masse et les chromatographes en phase gazeuse ou liquide ?

- Comment établir les règles de vieillissement des canalisations en matériaux composites qui permettent de simuler sur un centre expérimental des règles de vieillissement accéléré ?

Ainsi à la fois si on cherche à faire la synthèse des techniques mises à disposition de l'exploitant, ce qui est un des buts de ce colloque, mais surtout à évaluer les éléments de succès d'une technologie en cours de développement, il est **primordial de prendre un peu de recul**, et de hauteur et de s'interroger sur les conditions d'application de ces nouvelles techniques, sur le pourquoi et le comment.

III - LES LECONS DE L'EXPERIENCE

La première piste à suivre pour éclaircir l'avenir est de tirer les leçons d'un passé même récent.

Il est bien sûr inépuisable. Reprenons un instant quelques uns des exemples cités pour en extraire les éléments importants :

1) Les applications de l'informatique dans le métier de la distribution d'eau nous ont appris à gérer une contrainte et à résoudre un problème.

La **contrainte** est celle d'une **organisation** très **éclatée** dans l'espace de la Ville, du système de distribution d'eau, ce qui signifie :

- toujours un nombre élevé d'appareils de mesure locale ce qui n'est économiquement possible que par une standardisation, une pérénité de l'équipement et une intégration poussée ;

- presque toujours un problème de transmission automatique par une combinaison astucieuse : ligne spécialisée, ligne commutée, liaison radiotéléphone ;

- et souvent un problème d'alimentation en énergie avec un coût d'installation prépondérant par rapport au coût d'achat direct de l'équipement.

Au fond cette contrainte nous révèle les trois critères essentiels à respecter dans la conception des systèmes appliqués à nos métiers : **décentralisation, hiérarchie et secours.**

Le **problème** essentiel réside bien sûr dans la contradiction entre la rapidité de l'évolution de la technologie informatique, électronique et la nécessaire progressivité des mutations admissibles. Une mauvaise gestion de cette donnée **temporelle** conduit automatiquement à un gaspillage financier (et des matériels) sans parler de l'impératif de continuité qui s'impose à un service public.

La GENERALE DES EAUX a ainsi été conduite d'une part à dissocier la part "matériel" rapidement évolutive de la part "logiciel" qui elle, représente la stabilité du métier de distribution d'eau, puis à réaliser le logiciel Lerne multiétagé respectant cette approche de **standardisation modulaire** qui seul dans le métier de l'eau, au contexte évolutif, permet d'organiser des procédés économiquement performants.

2) Le retour de la biologie dans le traitement de l'eau ne peut s'expliquer en profondeur au delà des gains en exploitation (diminution des adjuvants chimiques ou des sous-produits) au delà de la qualité du traitement (puisque c'est aussi l'élimination des micro-polluants qui a remis en selle les processus biologiques) que par une bonne adéquation aux **variations** de la matière première. De plus les procédés biologiques se sont insérés facilement dans les ouvrages existants (élimination de l'ammoniaque sur le filtre à sable, meilleure connaissance de l'efficacité biologique du couple ozone-charbon actif en finition, etc...) ce qui permet de mettre en évidence à la fois la nécessaire **flexibilité** des ouvrages pour réagir à ces variations de la matière première et l'utilité de mettre en oeuvre les effets d'interaction et de **synergie** entre les différentes étapes du traitement des eaux.

Les deux derniers points dépassent en fait le simple cadre de ce nécessaire recours à la biotechnologie autour de laquelle (sans exclusivité) nous voyons quant à nous s'organiser l'usine de traitement de l'eau de demain. Ils mettent en évidence une des grandes caractéristiques de **l'Ecole Française de l'Eau** (Fig. 7), à savoir **l'art** de la **composition séquentielle des ouvrages** à la fois dans l'espace et le temps, en introduisant systématiquement la flexibilité des ouvrages.

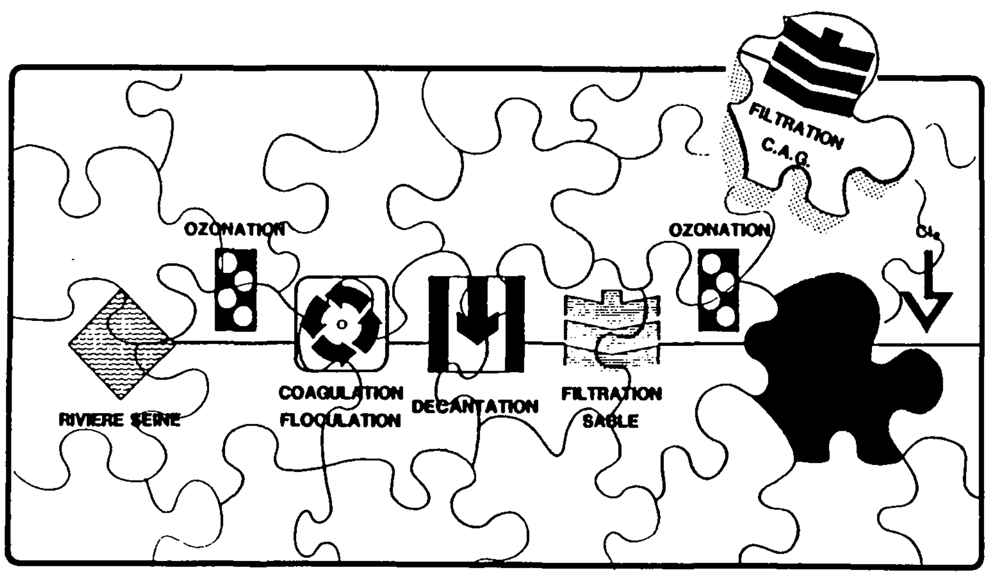

Fig. 7. Une des grandes caractéristiques de l'Ecole Française de l'Eau repose sur l'art de la composition séquentielle des ouvrages, à la fois dans l'espace et dans le temps, en introduisant systématiquement la flexibilité des ouvrages.

3) Nous avons déjà souligné que les systèmes experts constituent une bonne solution pour des problèmes complexes qui se résolvent difficilement par des programmes informatiques classiques. C'est d'ailleurs ce double impératif de facilité d'utilisation et d'adaptabilité au changement de la connaissance qui ont imposé ce nouvel usage des moyens informatiques.

Or, certaines des **caractéristiques essentielles** du métier de l'eau sont mal prises en compte, dans une utilisation classique des ordinateurs et ces méthodes conduisent à un cheminement algorithmique trop lourd nécessitant des méthodes trop coûteuses et des ordinateurs trop puissants. On peut rappeler :

- aspect émietté car nécessairement local de la gestion de ces services

- nécessaire adaptation au terrain des solutions techniques générales (diversité des solutions)

- mise en oeuvre de façon permanente de technologies de pointe diverses faisant appel à une multitude de disciplines scientifiques (biologie, physico-chimie automatisée, statistiques, olfactométrie, etc...)

Mais la caractéristique essentielle de ce métier est bien la nécessaire **responsabilité de l'opérateur** local qui seul peut s'adapter aux circonstances locales pour améliorer le service rendu à l'usager afin d'aboutir à la meilleure qualité aux meilleurs prix, c'est-à-dire en somme à savoir mettre en oeuvre une **connaissance** opérationnelle **adaptée.** Et seuls les systèmes experts peuvent aujourd'hui capter cette connaissance.

Les systèmes experts seront ainsi probablement un moyen privilégié de l'entreprise de service du métier de l'eau et de valorisation de l'intelligence de ce métier. Il ne s'agit pas de savoir écrire un Larousse médical dans nos métiers. Il s'agit de former de bons médecins généralistes possédant cette "expertise opérationnelle de généraliste" que l'on oublie que trop.

On peut même probablement parler d'une identité d'approche entre les systèmes experts et le métier de l'eau où en effet une démarche empreinte de **finesse** (au sens de Pascal) s'impose pour répondre à la finesse de l'échelle (locale) et à la finesse des problèmes n'est-ce-pas ce que les systèmes experts cherchent à conférer à un ordinateur ?

IV - LE CHEMIN DE L'INNOVATION

Les leçons de l'expérience ne sont cependant qu'un volet imparfait éclairant les nécessaires conditions d'apparition d'une technique nouvelle. Il faut appréhender plus en profondeur le pourquoi et le comment et répondre à des questions comme :

- Y a-t-il des procédures générales à respecter ?

- Quels sont les lieux de passage obligés ?

- Quelle est la **chaine** de l'innovation à mettre en place entre un utilisateur final exploitant un réseau d'eau donné et un industriel promotteur d'une technologie de pointe tout juste en train de sortir des limbes de la recherche fondamentale ?

- Quel est le délai prévisible de l'innovation ?

- Qui doit être moteur et à quel moment ?

Or il nous semble, et nous l'avons déjà évoqué sur les exemples précis cités plus haut, que le métier de l'eau est tellement spécifique que le **chemin de l'innovation est facilement caractérisable** dans l'espace et le temps, **étroit et difficile** et que c'est la méconnaissance de certaines des règles élémentaires mais ingrates qui expliquent la majeure partie des retards voire des échecs de certaines technologies prometteuses.

Nous ne reviendrons que sommairement sur la spécificité du métier de l'eau largement développée. S'il fallait condenser à l'extrême, il faudrait retenir :

- La **diversité** des situations locales qui impose à toute nouvelle technique une part importante d'adaptation à tous les cas particuliers ;

- La **variabilité** de la matière première dans le temps ;

- La **prudence** des gestionnaires d'un service éminemment vulnérable en qualité et en quantité d'eau ;

- La **lourdeur** des investissements dont le renouvellement est très lent et **l'importance** en France de ce **parc d'usines** de traitement et des **canalisations ;**

- Le poids des hommes et le **sens de l'histoire** devant cet héritage complexe où se succèdent des objectifs, des techniques, des contraintes fluctuantes.

Si on cherche à décrire ensuite, même très sommairement, le chemin de l'innovation en insistant sur les éléments moteur et les erreurs à ne pas commettre, on peut reconnaitre 4 ou 5 étapes indispensables :

- **Assimilation du concept technique** par l'exploitant. Phase de connaissance. Une solution technique toute faite n'existe pas. Eviter les à priori d'une transposition d'idées générales d'un métier à l'autre. Ne jamais travailler comme un bureau d'étude en chambre (ce qui peut être tentant compte tenu de la complexité des phénomènes à analyser).

  Une bonne solution est souvent la désignation au sein de l'entreprise gestionnaire d'un tout petit groupe de chargés d'étude, voire d'un individu, animateur général. Parallèlement l'entreprise organise ses compétences au sein d'un club informel d'utilisateurs, ce qui garantit une diversité d'approche et permet l'assimilation d'un langage technique commun.

- **Définition par l'aval des objectifs** recherchés par cette nouvelle technique en fonction de son impact sur l'un des critères essentiels du service (la sécurité, la fiabilité, le confort de l'habitat, la productivité) véritable refaçonnage du produit technique. Il y a souvent intérêt à formaliser cette étape sous forme d'un véritable cahier des charges du produit, premier document contractuel de l'innovation.

- **Elaboration du produit sous forme de prototype,** de "maquette". Une expérimentation pilote (passage à l'acte) rapide est **indispensable** (Fig. 8). Elle est nécessaire pour tester l'adaptation de la solution technique au marché et pour mieux cerner les contraintes. Ne pas pour autant sous-estimer les effets d'échelle et les étapes intermédiaires (on ne passe pas automatiquement d'un pilote de 5 l/h d'un laboratoire à un pilote de 5 m^3/h sur le terrain).

  L'intérêt est de formaliser cette notion **"d'îlot de technicité avancée"** sur le terrain et d'organiser le service et la formation des hommes en conséquence.

  Cette expérimentation, de plus, doit pouvoir servir de première référence commerciale en cas de succès. Enfin même en cas de succès, l'industriel ne doit pas anticiper le marché qui n'existe pas encore.

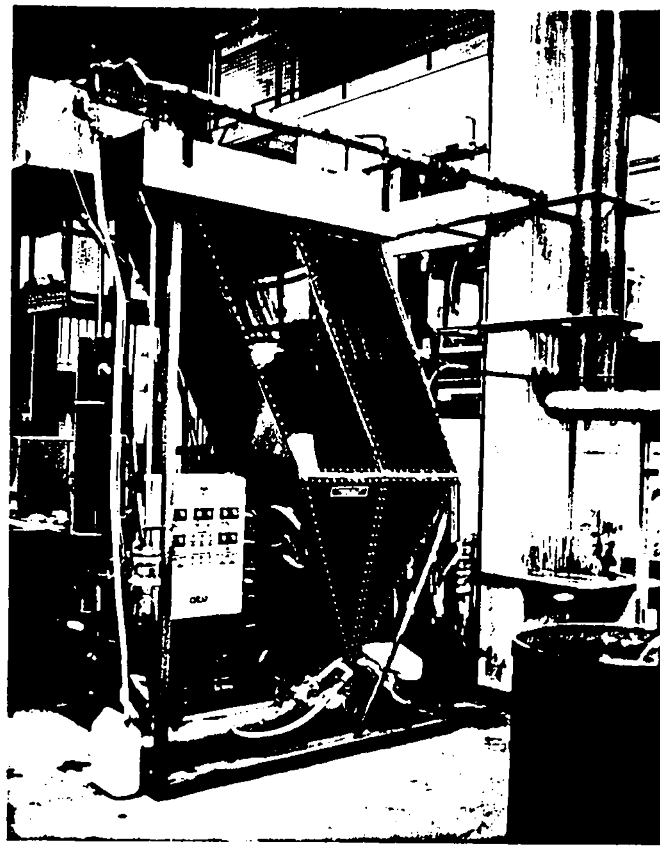

Fig. 8. Vue d'un décanteur-lamellaire (pilote) au Centre de Recherche de la GENERALE DES EAUX à Maisons Laffitte. Une expérimentation pilote rapide est indispensable : elle est nécessaire pour tester l'adaptation de la solution technique au marché et pour mieux cerner les contraintes (document ANJOU RECHERCHE)

- **Diffusion lente** et complexe de cette nouvelle technique. Prudence de l'exploitant et spécificité locale. Plusieurs mois d'exploitation de la 1ère référence seront souvent nécessaires pour mieux connaitre la fiabilité de cette solution. Il faut, de plus, habiller le produit pour le rendre accessible à tous les exploitants et transposer le savoir faire. Le décollage au marché est très lent et sur plusieurs années. De plus, l'industriel, ne doit pas surestimer le marché.

- **Diffusion internationale** souvent **difficile** alors qu'elle est indispensable pour obtenir la taille du marché suffisante. La qualité du service, la sécurité, les normes réglementaires, la protection du milieu sont en effet variables d'un pays à l'autre. "L'économie" d'une innovation doit être largement redéfinie dans chaque pays. Des écarts supérieurs à une dizaine d'années d'un pays à l'autre, même de niveau de vie équivalent, peuvent être constatés. Des différences de cultures interviennent : on peut citer par exemple les goûts et saveurs de l'eau où les exigences d'un consommateur français et probablement européen opérant consciemment ou inconsciemment une comparaison avec les eaux minérales, n'ont rien de commun avec celles d'un consommateur américain où le goût du chlore apparait comme le meilleur garant de la salubrité de l'eau...

Pays par pays, l'économie d'une innovation dépend ensuite largement des **"règles du jeu" définies par les Pouvoirs Publics.** Pour ce qui est de la France, on peut citer les 3 ou 4 règles du jeu suivantes qui permettent d'élever le degré de performance des techniques :

- La contrainte de la compétition et la règle du concours qui (heureusement) est souvent un aiguillon pour l'innovation..

- La "bonne" vérité des prix du système français qui rend bien l'usager comptable des 3 volets du cycle de l'eau : sa mise à disposition, sa gestion, son retour au milieu naturel.

- Les nouvelles normes européennes qui en eau potable ont permis de rehausser le niveau de qualité à atteindre, et qui dans le domaine de la ressource en eau individualise, paramètre par paramètre, les efforts à faire dans le cadre d'une démarche d'objectif de qualité.

En résumé quelles caractéristiques générales de ce chemin de l'innovation peut-on isoler ?

- **Un pilotage par l'aval** primordial à la fois au niveau de la définition du produit et de sa première référence sur le terrain.
- **Une souplesse** indispensable à l'industriel pour adapter son produit au cas particulier par une **standardisation modulaire** et évolutive qui est au coeur de la rentabilité en ce domaine.
- **Un délai long :** une innovation technique importante met environ dix ans avant de se diffuser.
- **Un marché difficile** et souvent plus étroit que les besoins potentiels le laissent envisager.
- **Un métier d'ensemblier** qui s'exprime dans un art de la composition séquentielle des ouvrages avec la recherche à priori de la **flexibilité.**

V - EN CONCLUSION : Le métier d'entrepreneur ensemblier de l'innovation

De plus l'innovation dans le métier de l'eau impose des acteurs spécifiques. On verra apparaitre bien souvent l'utilité voire la nécessité d'un opérateur gérant l'interface entre le gestionnaire de service et les possibilités technologiques avec un véritable rôle **d'entrepreneur-ensemblier de l'innovation,** si on veut réaliser un couplage direct "nouvelle technologie - marché", faire prendre en charge la première expérimentation par un exploitant, "shunter" autant faire se peut les résistances internes à l'innovation.

Encore faut-il une taille minimum, une organisation adéquate ou une diversité suffisante de cas d'application pour créer et maintenir ce **métier d'interface.**

Dans ces conditions quelles conclusions peut-on en tirer ?

Est-ce l'industrie de pointe qui tire le service, ou est-ce le service qui tire l'industrie de pointe ?

La réponse est bien sûr, et notre exposé l'aura peut-être montré, ni dans un sens ni dans un autre. Il y a autostimulation, lien matriciel, autofécondation. L'innovation reste en fait une des meilleurs courroies d'entrainement de ce métier.

En tout état de cause les acteurs principaux de cette chaine de l'innovation restent les hommes. Le véritable critère discriminant d'une entreprise de service qui gagne dans le métier de l'eau est le degré d'ouverture à l'innovation que manifestent les responsables locaux d'un service d'eau.

C'est d'ailleurs pourquoi toute politique d'innovation doit s'accompagner d'une politique permanente de formation des hommes à tout niveau, voire de l'acceptation d'une "surcapacité intellectuelle" permettant de capitaliser de la valeur ajoutée aux éléments essentiels de ce métier d'opérateur.

Dans ces conditions, les plus grands gagnants de ce métier sont les hommes, leur formation et plus généralement leur enrichissement :

- Qualité de l'homme de développement d'abord, car ce sont ceux qui voient s'exercer le frottement de ces deux approches et qui enregistrent une quintescence de ce métier.
- Enrichissement des hommes du métier de l'eau. Devant la difficulté quotidienne des tâches à accomplir, par leur volonté d'améliorer la qualité du service offert aux usagers et les conditions de travail de ses préposés, ceux-ci apprennent en effet à appliquer dans des situations très diverses une diversité de techniques.

WATER SUPPLY AND ENERGY CONSUMPTION

Walter Würth, Member of the Cocodev/IWSA, President of the Commission for appropriate technologie of the SGWA
c/o Electrowatt Engineering Services Ltd. CH-8022 Zurich, Switzerland

ABSTRACT

Energy is a necessity for the running of water works and the security of energy supply may have an importance for the extensions of water works due to population growth. Impact and influences of power plants on water works have to be carefully studied. Necessity of a clear policy to be pursued as to the future energy supply of water works.

KEY WORDS

Energy demand for water works; specific consumptions; economizing of energy; evolution due to population growth; impact of power plants on environment and water works; securing future energy supply.

INTRODUCTION

Energy supply is essential for the running of water works; this is for transportation, pumping and treatment of water, control and command of the installations. This fact is seldom mentioned because energy supply without any limitation is taken for granted and because it represents only a small percentage of the total of operation costs.

Electric energy is mostly provided by public services. In some cases it may be produced by diesel engines or generating sets.

DEMAND OF ENERGY FOR WATER WORKS AND SPECIFIC CONSUMPTIONS

Energy, mainly as electric energy is used in water works for the following services:

- pumping of water from groundwater or surface water to the treatment sites or to the reservoirs
- pumping of water for transportation and from the treatment sites to the reservoirs
- water treatment by filtration and aeration, special treatment processes such as Reverse Osmosis (R.O.) and desalination (thermal energy)
- general services as control and command, lighting, auxiliary services

The specific demand may vary largely for pumping as well as for treatment, depending on the pumping heads and on the treatment steps.

Even nowadays there are large cities which are supplied by spring water from mountains, flowing by gravity, and with no need of pumping or treatment (for example Munich, Rome).

Other cities need large pumping stations for their water supply such as Caracas (Venezuela) which has to pump its water over a head of 800 m, implying an energy demand of about 3.5 kWh/m3. Another example is the region of Abba, in Saudi-Arabia, situated at an altitude of 2290 m o.s. which is supplied with dessalted sea water. This means about 10 kWh/m3 for pumping only.

As an average however, a water supply taking water from the groundwater or from surface water and pumping it into the distribution network, with a minimum of pressure requirements and taking into account a rather flat topography, will need about 0.2 kWh/m3 for pumping.

For water treatment the requirements may vary in a large range, depending on the treatment.

TABLE 1 SPECIFIC ENERGY CONSUMPTIONS FOR WATER TREATMENT

	KWh/m3
treatment in a filtration plant	0.10
ozone treatment	0.10 - 0.20
elimination of nitrates by. R.O.	1.00 - 1.80
desalination by R.O. without energy recovery	10.00
desalination by R.O. with energy recovery	6.50
desalination, single purpose MSF heat input 294 kJ/kg + 3.7 kWh/m3	85
desalination, dual purpose MSF heat input 155 kJ/kg + 3.7 kWh/m3	47

SWISS WATER WORKS

In Switzerland 43 % of drinking water, totaling 1'150 millions m3/a, is taken from wells, 40 % from groundwater and 17 % from surface water (lakes). Therefore 57 % of the water has to be pumped, in a first stage up to the treatment plant - if necessary - and in a second stage up to the reservoirs and the distribution network.

The specific energy consumption depends on the pumping head and on the necessary treatment steps:

TABLE 2 SPECIFIC ENERGY DEMAND IN SWISS WATER WORKS IN KWH/M3

for:	City of Zurich	Average of all waterworks	(maximum)
pumping	0.55	0.12 - 0.40	(1.85) *)
treatment	0.10	- 0.10	
general services	0.05	0.03 - 0.05	
total	0.70	0.15 - 0.55	(2.0) *)

*) important pumping heads of more than 200 m.

For a city like Zurich with a population of 400'000, the energy consumption amounts nevertheless to the important figure of 50 GWh/a. For the whole of Switzerland, with 6 mio. inhabitants, the energy necessary for the water works may be estimated to about 350 GWh/a. This energy corresponds to the production of a hydro power plant of 120 MW working 3000 h/a or of a thermal power plant of 60 MW working 6000 h/a. These figures show the importance of a secure and uninterrupted energy supply for the water works.

WORLD WIDE SITUATION

The operation of water services relying on natural water sources or in rural conditions, this is without distribution net, may require no energy at all.

For water distributions using groundwater or surface water electric energy is a necessity. We may estimate a consumption between 0.10 and 0.20 kWh/m3 for pumping only. With a total volume of about 70'000 million m3/year to be pumped, nowadays the energy needed amounts to about 10'000 GWh/a.

The energy required for water treatment is much less, perhaps 20 to 30 % of the pumping consumption, i.e. 0.03 to 0.05 kWh/m3. For desalination however, the energy demand amounts to 43 to 81 kWh-thermal/m3 for evaportion only.

ENERGY ECONOMIZING MEASURES IN WATER WORKS

Water works in industrialized countries try to reduce water consumption as well as energy consumption. These targets may be achieved by the following measures:

- reduction of water consumption by the users, recycling of water in industries
- leakage control and reduction
- installation of water meters, application of adecuated tariff politics
- using low-tariff electric energy for reservoir-pumping
- installation of water turbines in gravity flow sections to produce electric energy where this is possible

FUTURE EVOLUTION

In industrialized countries the population as well as the specific water consumption will increase very little; saturation is almost attained. Some services note even a slight diminution of water consumption - and therefore also of energy - due to measures of economizing, recycling of water in industries and leakage control. Due to this policy these water works will not have an increasing energy demand.

If we take a look at the future evolution of water supply in developing countries we must discern serveral very different aspects which we will discuss in the following:

- future evolution will be different for developing countries than for industrialized countries, in fact, industrialized countries have achieved a high degree of development, performance, technology and experience in water supply:
  -- they have been developed for a high specific water consumption rate
  -- they have a high realiability as to the supply capacity
  -- they have planned and realized the extension of their installations by addtional treatment lines so as to be able to cope immediately with new pollution spills as soon as they appear.
  -- they dispose of a secure and redundant energetic supply with sufficient reserves for emergency cases, as for example redundant feeders.

  On the other hand water supply in developing countries generally does not dispose of a high degree of performance due precisely to the fact that these countries are in a developing state:

  -- the specific consumption rate is on a low level, new industrial developments will require additional supply capacities
  -- the actual supply demand is not always fully guaranteed.
  -- they dispose just of a minimum of necessary treatment lines
  -- the supply of electric energy may be sufficient but not optimum

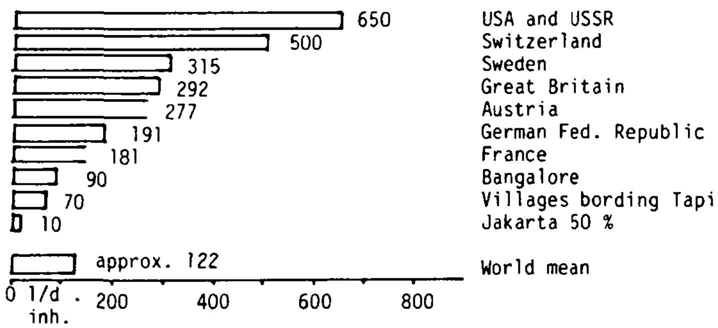

Fig. 1 Mean daily water consumption per capita
(according to water works Zurich, 1985)

- Growth of population - increasing water demand
  The problem of the increasing number of population and therefore of increasing volume of drinking water to be provided is well known.

  As natural water sources become insufficient with increasing water demand, the water works have to make use of remote sources. This implies transport of water, sometimes also pumping the water from lower levels. The consequence is an increase of electric energy demand.

- Growth of the city population
  We have all heard about the alarming reports and documents published by several international organizations on the exuberant and uncontrolled growth of large cities (UN-World Comission for Environment and Development, Worldwatch Institute WWI: Worldwatch Paper 77, Washington 1987 "The Future of Urbanization, Facing the Ecolcgical and Economic Constraints" by Lester R. Brown and Jodi L. Jacobson):

  In 1950 : 600 million people or 14 % of the world population lived in cities (17 % for developing countries)

  In 1986 : 2000 million people or 43 % of the world population lived in cities

  In 2010 : we reckon with 3620 million people or 72 % of todays world population living in cities, or 52 % of the 6990 million population of 2010. For developing countries these figures would be 2000 million people or 40 %.

The following diagrams show the predicted increase of world population and the expansions of large cities. These expansions may of course be stopped or slowed down by eventual economical or ecological constraints.

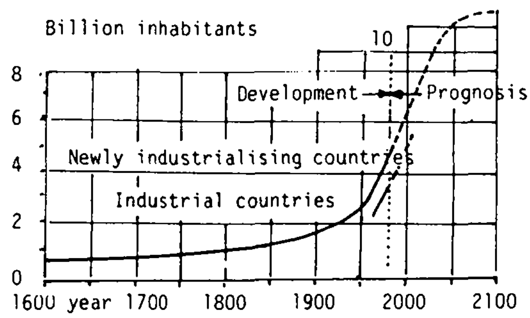

Fig. 2 Increase of world population
(according to water works Zurich, 1985)

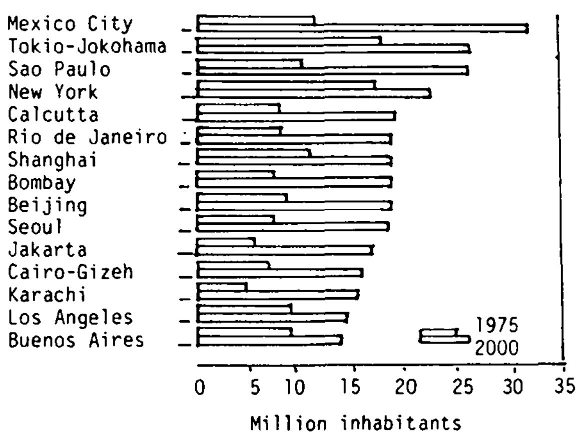

Fig. 3 Expansion of large cities
(according to water works Zurich, 1983)

In parallel to this alarming situation, we are confronted with the fact that these additional town's people settle down in illegal and uncontrolled slums getting on with poor or no water supply and no waste disposal at all. These cities are therefore confronted with the problem to produce and supply the necessary drinking water to the consumer within drinking water standards.
Apart from the problem of obtaining a sufficient amount of water, the catchment, treatment and transport of the water requires still more electric energy.

Summarizing these facts, we come the the following situation, regarding especially the problem of electric energy:
Industrialized countries have attained a level of water supply, which will not demand further development. On the contrary, a reduction of the energy consumption may be possible by means of
- reduction of leakage
- reduction of specific consumption
- recycling (industries)
- using night current for pumping
- recuperating the fall of water supply by installing a turbine to produce electric energy.

Developing countries are faced on the contrary with additional energy consumption due to:
- increasing specific consumption
- increasing water demand for new industries
- increasing capacities in order to guarantee the water supply at any time
- increasing capacities of treatment and for new treatment lines

Growth of population / increasing water demand:
The additional energy consumption will:
- be proportional to population growth, and
- depend further more on the requirements of transport, lifting and treatment of water from remote sources

Growth of city population:
In comparison with the general growth of population, the growth of city population will generate higher specific water consumption. In other words, the consumption of rural population is less than the consumption of city population, the same people moving to the city will need more water.

How do we plan our future development ?
We should consider not only the additionally needed volumes of water, but also the additional energy demand for the following items:

TABLE 3 CHECKLIST FOR ADDITIONAL ENERGY DEMAND

Item	Determinant aspect	Energy demand for water supply
- extension of existing installations	- adjustment of specific demand	+
	- full development of treatment and safe supply	+
- growth of population	- growing water demand	+
	- remote sources (transport)	+
	- pumping from lower levels	+
	- new treatment lines	+
- growth of city population	- growing water demand	+
	- increase of specific demand	+
	- remote sources (transport)	+
	- pumping from lower levels	+
	- new treatment lines	+
	- new industries	+

These items have to be examined not by a global evaluation, but considering each particular domain implicated. This planning will yield the new energy demand.

Taking an example: an urban population of 1 million people, with 150 l/d or 55 m3/a specific water consumption, has an annual water demand of 55 million m3. Assuming a specific energy demand of 0.15 kWh/m3, the total annual demand of electrical energy will be 8 GWh/a for pumping only.

Figures published by the International Reference Centre for Community Water Supply and Sanitation show that in 1985 about 200 million people are not covered with urban water supply. The corresponding energy demand would be about 1'600 GWh/a. These figures show the importance of energy supply in water works.

WATER, ENERGY AND ENVIRONMENT

Water works will not only be concerned about sufficient water supply and energy supply but also about interactions which take place between them and the plants generating electrical energy. Electricity is produced by hydro-power plants and by thermal power plants. These may operate on coal, oil or nuclear reactor basis.

The manifold influences or impacts of power stations on water works are known in a general way. In view to the future it is worth while to look more closely at them, especially because today both, water works and power plants use to an ever higher degree the water at their disposal. Hydro-power plants use water directly for their production, by diversion through canals, galeries and penstocks, by impounding in storage basins and reservoirs. Thermal plants use water for cooling purposes, but may cause water pollution also by air pollution or other indirect influences such as transport and storage of fuel. So, direct and indirect pollution of water is the consequence of this high degree of utilisation.

In future much more attention has to be paid to this impact, not in a way of condemning power stations - we need their electricity for our water works - but in a way of co-operational mutual understanding and support, in order to do away with the danger of pollution of water needed for drinking purposes or at least to reduce this impact below acceptable limits. It has to be said that the solution to these problems can always be found in a satisfactory way for all involved parties, as examples in Switzerland have shown.

Hydro-power plants :

The following list in table 4 compiles influences and changes in the water resources due to hydro-power plants, which may influence the water quality and must be examined and checked by waterworks on a long term basis and with an outlook to the future:

TABLE 4 CHECKLIST FOR IMPACTS BY HYDRO-POWER PLANTS

Item	structure	to be examined and checked
Landscape	storage basins	- maintenance of a natural landscape with natural plantations (protection of groundwater) - sufficient residual rate of flow to be let in the natural water courses (water flow) - influence of evaporation in hot countries (climate) - influence of eutrophication of the water in hot countries (water quality)
Groundwater	storage basins, canals	- the water level in basins and canals will increase infiltration and will raise the groundwater level by infiltration (agriculture, groundwater quality) - tail water canals will lower the groundwater levels by exfiltration (agriculture, capacity of wells) - changes of the groundwater level will influence the movement of groundwater flow and may therefore influence the quality of water (geology, residual waste deposits, a.o.)
Waters	weirs, canals, tailwater canals	- changes of natural waterflow
	storage basins	- accumulation of sludge and rubble at the bottom, to be flushed by flood or for cleaning the reservoir (water quality, fishery) - the storage of flood waters may influence the natural water regime in a positive sense compensating low water flow - deterioration of water quality by long time storage
Fishery	weirs, storage basins	- the construction of weirs and reservoirs will alterate the actual fish population. The changes may be seen in a positive or a negative way and must be studied in detail.

Thermal power plants:

The checklist for thermal power plants is quite different from the hydro-power list. Water is used mainly for cooling purposes, but there are other influences which have to be looked at and which have their long term influence, such as air pollution and soil pollution:

TABLE 5 CHECK LIST FOR IMPACTS BY THERMAL POWER PLANTS

Item	structure	to be examined and checked
Waters	cooling water structures	- direct cooling with water will warm up the water. Some countries have edited temperature limits by law (water quality) - indirect cooling with cooling towers uses much less water than direct cooling. The discharge of the cooling tower has to be controlled as it may be charged with pollutants.
Groundwater	buildings, fuel storage, wells	thorough examination of all risk points: - percolation of chemicals, fuel (for fuel plants, for emergency diesel units) and polluted water into the soil - transportation of fuel by railway or road, unloading areas are risk points - storage sites for coal, fuel coal cinders and ash are also risk points
Air pollution Soil pollution	chimneys for coal or fuel fired stations	- outfall will cover landscape and waters, a sufficient air purification has to be provided (water quality)

In each case of new projects or extensions of hydro or thermal power plants, possible impacts have to be carefully studied and solutions worked out to eliminate negative influences on water supply. In some cases an additional protection of the water supply installations may be adequate and/or necessary.

OUTLOOK TO THE FUTURE

Further to a secure and continuous energy supply, water works shall elaborate and pursue for their future a clear long term policy leading to the following objectives:

- reduction of energy consumption where water consumption has been stabilized by appropriate means like economizing, recycling (industries), leak detection
- securing the increasing energy supply for coming years, where population growth and increase of specific water consumption has to be coped with
- careful study of the impact of electrical power plants on the installation of water works, in order to handle economically our global resources.

Therefore the objectives for the future development regarding energy supply are twofold:

- to assure the energy supply and
- to protect the water works from impacts of power plants

EMERGING U.S. WATER TECHNOLOGIES

Kenneth J. Miller
Vice President and Director of Water Engineering
CH2M HILL Consulting Engineers
P.O. Box 22508
Denver, Colorado, U.S.A. 80222

INTRODUCTION

This paper concentrates on new and emerging water treatment technologies in North America as we approach the 21st century. Much of the motivation to develop these technologies is derived from our ability to measure water contaminants in the parts-per-billion range and our inability to understand the toxicology and risk associated with these contaminants.

An additional motivation was the recent passage by the U.S. Congress of the 1986 Amendments to the Safe Drinking Water Act. These amendments will foster new regulations concerning organic and inorganic contaminants. The U.S. Environmental Protection Agency (EPA) has developed a compliance schedule extending over the next several years that has already focused and prioritized the water supply research.

The overview of technologies presented in this paper are specific CH2M HILL projects and current research conducted by utilities, consultants, academia, regulatory personnel, and water supply equipment manufacturers in the United States.

ORGANICS REMOVAL OPTIONS

Buffalo Pound Water Treatment Plant, Saskatchewan, Canada

The Buffalo Pound Water Treatment Plant supplies potable water to more than 200,000 people in the cities of Regina and Moose Jaw, Saskatchewan, Canada. The raw water source is Buffalo Pound Lake, an 18-mile-long man-made lake with an average depth of only 10 feet. Extensive blooms of algae, notably blue-green varieties such as anabaena and microcysts, predominantly occur in the summer creating an objectionable musty or grassy odor. The lake water threshold odor number (TON) values typically exceed 10 in the summer. At times, an anabaena bloom in excess of 30 million cells per liter have created TON values as high as 55.

During the winter, Buffalo Pound Lake is covered by a thick layer of ice. In some years, algae blooms have occurred under the ice with resulting taste and odor problems throughout the year. The organic content is relatively high on a year-round basis, with the total organic carbon (TOC) content varying from 3 to 10 mg/l.

In 1980, CH2M HILL was retained to evaluate options for upgrading the Existing Buffalo Pound Water Treatment Plant to improve its ability to produce a safe and palatable product water. Initial options that were investigated included alternate intake sites, different oxidants such as potassium permanganate and ozone, powdered activated carbon, and granular activated carbon (GAC). GAC was selected as the preferred process; it was the only process that would produce the high quality water desired.

The GAC contactor system design was completed in 1983, and the system was constructed and ready for operation by the summer of 1985. Meanwhile, work proceeded with the development, design, and construction of a carbon transfer and regeneration system that was commissioned in October 1985. Thus, the spent carbon from operations during the summer of 1985 could be regenerated before the summer of 1986.

The GAC contactor system has a 32-mgd capacity. Planning is underway to expand the capacity to 45 mgd. Eight 630-square-foot gravity contactors are normally charged with 10 feet of 8 x 30 mesh coal base GAC, which provides an empty bed contact time of 15 minutes at maximum flow. The contactors were constructed to operate downstream of the existing plant filters; filter effluent is lifted to the top to the GAC contactors by 8-foot-diameter screw pumps.

The contactors contain approximately 1,500,000 pounds of GAC, which is typically regenerated once per year. Large, pressurized blow tanks transfer the GAC to the regeneration system with minimum attrition, which is crucial to minimizing the overall operating costs. The regeneration furnace is a Westvaco two-stage fluid bed system with a capacity of 14,000 lb/day. The system has performed quite well and within specifications. The adsorptive capacity of the GAC, as measured by Iodine Number, was essentially fully restored by regeneration of the carbon with total attrition losses estimated at about 6 to 8 percent. Total operating costs, including makeup carbon, were equivalent to about 15 cents per pound compared to 85 cents per pound for new carbon. The annual savings is approximately $1 million, which makes the $3-million regeneration system a very good investment.

The GAC system has performed very well for the first 2 years even though the odor level in the raw water has been much greater than average. In both 1985 and 1986, the GAC removed the odor to nondetectable levels for the first 2 to 3 months of summer operation, after which low-level breakthrough occurred at TON levels of 1 to 3. Average performance for each season resulted in more than 90-percent reduction in TON, 65- to 75-percent reduction in TOC, and 66- to 78-percent reduction in total trihalomethanes. Data from the plant-scale performance history continues to be evaluated and applied to the operation of the system to enhance its performance. Perhaps the best measure of the system's performance is the positive response from officials and the public who claim vastly improved palatability of the water.

CH2M HILL was recognized for its work on this project by the Association of Consulting Engineers of Canada and the Canadian Consulting Engineer Magazine, which selected the Buffalo Pound Taste and Odor Control Project for an Award of Excellence as one of the outstanding civil engineering projects in Canada in 1986.

Harwood's Mill Water Treatment Plant, Newport News, Virginia

The Harwood's Mill Water Treatment Plant gets its raw water supply from the Harwood's Mill Reservoir, a terminal raw water reservoir that is fed by the Chickahominy River. The Chickahominy River watershed is heavily wooded with many low-lying swampy areas. Consequently, the water has a relatively high concentration of naturally occurring organics that result from decaying vegetation. This creates a relatively high concentration of TOC, total trihalomethane formation potential (THMFP), and a moderate to high color content.

In planning the new Harwood's Mill Water Treatment Plant, the City of Newport News staff developed a goal-oriented strategy to meet current as well as future drinking water regulations. The key goals of treatment process selection and design are:

- Design for a total trihalomethane (THM) concentration of 50 µg/l
- Design for a free chlorine residual in the drinking water (no chloramine)
- Provide the maximum flexibility possible in both plant layout and process design to facilitate meeting future drinking water regulations that may emerge

The City chose the THM goal anticipating that the current EPA Maximum Contaminant Level (MCL) of 100 µg/l will soon be reduced. The use of free residual chlorination stems from the City's desire that microbiological safety of the drinking water in the distribution system should not be compromised by relying upon an inferior disinfectant.

The key elements of the new 25-mgd water treatment plant, expected to be in operation this year, satisfy all of the goals except that of meeting the THM concentration of 50 µg/l. The new plant includes preoxidation (with chlorine or potassium permanganate) and/or contact with powdered activated carbon, flash mixing, high-rate floc-blanket clarification, and then filtration.

Concurrent with the design and construction of the new plant, an intensive pilot plant program evaluated the dissolved organic removal capabilities of several innovative water treatment processes. The results of these pilot studies will ultimately determine the treatment processes and design criteria used for the removal of dissolved organics from the new Harwood's Mill Water Treatment Facility. The list below presents a range of water quality parameters that are typical for the Harwood's Mill Reservoir in the summer.

Temperature	15° to 29°C
pH	7.0 to 7.6
Alkalinity	50 to 76 mg/l as $CaCO_3$
Color	35 to 60 units
Turbidity	1.7 to 3.2 NTU
Algal Count	40 to 80 cells/ml
TSS	2.2 to 3.8 mg/l
VSS	1.6 to 2.3 mg/l
TOC	6.0 to 6.7 mg/l
THMFP (7 day)	570 to 645 µg/l
TOXFP (7 day)	1,500 to 2,200 µg/l

Key treatment processes that were further explored in the pilot studies were:

- High-rate floc-blanket clarification (IDI's Superpulsator)
- Low pH coagulation
- Addition of powdered activated carbon (PAC) to the high-rate floc-blanket clarification process
- Preoxidation testing both with and without the use of PAC
- GAC adsorption
- Biological activated carbon (BAC) or addition of ozone just ahead of the GAC

Low pH coagulation. Bench-scale studies conducted prior to the pilot operations indicated that alum performed slightly better than iron salts in reduction of turbidity, color, and dissolved organics. Furthermore, the lowering of pH either by an increase in alum dosage (beyond the optimum for good floc formation) or use of sulfuric acid along with alum demonstrated that significant further reduction in TOC and THMFP occurred down to pH 5.5. Pilot operations confirmed this finding, resulting in a reduction in TOC of 35 to 45 percent and a reduction of THMFP of 45 to 55 percent.

High-rate, floc-blanket clarification. Initial pilot studies of a pilot IDI Superpulsator indicated that settled water turbidity of 1 NTU or less could be maintained with hydraulic upflow rates of from 1.5 to 4.0 gpm/ft^2. No reduction in color removal or dissolved organic removal was evident with the higher rates. The floc blanket was found to be very stable over the duration of the pilot tests (about 16 months).

Addition of PAC to floc-blanket clarifier. PAC addition to the Superpulsator at a dose of 25 mg/l was studied first to determine that the floc blanket could be maintained in a stable operation without significant breakthrough of PAC in the clarifier effluent. After confirming that PAC leakage would not be a problem, organic removal performance was measured. THMFP reduction was found to be consistently near 60 percent when all chemical feed systems were operating properly.

Preoxidation with and without PAC. Without the simultaneous feeding of PAC, use of preoxidants such as chlorine dioxide and ozone were not found to significantly improve organic removal over the best data obtained without preoxidation. Use of chlorine, while helpful in minimizing clarifier effluent turbidity, had a detrimental effect on the THM concentration leaving the clarifier. Potassium permanganate used as an oxidant was not found to affect organic removal.

Use of preoxidants along with PAC was found to have a beneficial effect on organic removal. This effect was most dramatic with ozone. Use of preozonation at a dosage rate of 0.1 mg/mg TOC along with 25 mg/l of PAC and the necessary alum and polymer dosage consistently produced a THMFP removal of 70 to 80 percent. The results of these tests, when calibrated with the average distribution system THM, indicate that the process will approach the City's goal of 50 μg/l.

GAC adsorption. Passage of filtered water from the pilot system through a GAC contactor with an empty bed contact time of up to 30 minutes indicated that better than 95-percent removal of THMFP could be maintained for at least 60 days. The GAC adsorption process could easily meet the goal of 50 μg/l of THM and would provide the capability of meeting most of the emerging regulations anticipated for drinking water.

BAC (ozone + GAC). Application of ozone immediately ahead of the GAC adsorbers showed no advantage in performance based on removal or organics. However, there did appear to be a significant lag in the breakthrough of organics from the GAC process. The cost of adding ozone ahead of GAC does not appear to offset the cost savings in GAC due to extension of service between regenerations.

In summary, the basic treatment process being constructed at the Harwood's Mill Water Treatment Plant will provide the capability to meet most if not all of the anticipated drinking water regulations. The separate contact basins for preoxidation will also provide additional contact time for PAC. The ability to add acid and alum allows the optimization of the coagulation process for maximum organic removal with minimum sludge produced. The ability to add PAC to the Superpulsator will provide for the maximum adsorption of organics short of providing GAC. Finally, the design provides the flexibility for ultimately adding preozonation and GAC, if these additional processes become necessary.

Miami River Water Treatment Plant, Organics Control Facilities, Dayton, Ohio

Airstripping. CH2M HILL is currently designing an air stripping facility that will eliminate trace levels of volatile organic contaminants from the Dayton, Ohio, water supply. The facility will treat 28 mgd of groundwater from the Miami Well Field (expandable to 56 mgd) and will have provisions for treating additional wells in the future. The design will include well field piping and valves to transport water to the facility, booster pumps to convey water to the top of the air strippers, ten 12-foot-diameter air stripping towers, pumps to convey air-stripped water to the Miami Water Treatment Plant, a pump station building and appurtenances, and instrumentation and controls for both the well field and the facility.

Powdered activated carbon. To further protect water consumers, a PAC slurry storage and feed facility will be built. This facility will respond to emergency chemical spills that may occur in the well field and will consist of two 100,000-gallon glass-lined steel storage tanks and a chemical pumping building. The PAC slurry will be added to two accelerator basins containing alum and a polymer to develop a concentrated sludge blanket of PAC.

Construction of both facilities is scheduled to begin in the spring of 1987. The project is currently under bid.

CLARIFICATION/FILTRATION TECHNOLOGY

Hunter Creek Water Treatment Plant, Reno, Nevada

The Sierra Pacific Power Company (SPPC), water purveyor for the City of Reno, Nevada, contracted CH2M HILL in 1986 to design a new water treatment plant to replace the existing Hunter Creek Water Treatment Plant, which is constructed of open, earthen treatment ponds. The raw water supply originates in the Sierra-Nevada Mountains and is low in both alkalinity and total hardness. Turbidity is generally low unless exacerbated by precipitation events.

A pilot study at the site of the existing Hunter Creek plant evaluated the treatment efficiency of several filtration medias, the performance of lamella plate clarification, the potential use of in-line or direct filtration as a treatment alternative, and the effects of ozone application upstream of coagulant addition on water treatment performance.

Mobile pilot trailer. The studies were conducted in the CH2M HILL mobile pilot plant trailer. The 8-foot-wide by 34-foot-long trailer houses the tankage, equipment, and instrumentation necessary to operate and control ozonation, rapid mix, flocculation, clarification, and gravity filtration. The trailer components are flexible to allow configuration of the various unit processes into any desired treatment train. An onboard computer system aids in process control and monitoring as well as provides data handling requirements.

Lamella plate clarification. Lamella plate clarifier testing established design plate loadings of 0.33 gpm/ft^2 for summer peak demand and 0.22 gpm/ft^2 for spring runoff conditions. Clarifier effluent quality was maintained even when raw water turbidity varied from 12 to 60 NTU. Minimum clarifier effluent turbidities were 2.8 NTU for spring and 1.4 NTU for summer conditions. Surface overflow rates of 7.5 gpm/ft^2 for summer peak demand and 5 gpm/ft^2 for spring flows are substantially greater than conventional clarification overflow rates, which typically run at about 1 gpm/ft^2.

Seasonal direct filtration. In-line filtration consists of coagulation of raw water followed by filtration. Direct filtration is coagulation, flocculation, and then filtration. In-line and direct filtration studies determined that neither method could meet the finished water turbidity of 0.1 NTU. Filter runs prior to terminal headloss were shorter than the target of 18 hours for both methods of filtration. In-line filtration required less coagulant chemicals than direct filtration.

Raw water turbidity for the pilot tests was between 8 and 12 NTU. There is a possibility that in-line or direct filtration may achieve the 0.1 NTU target when the raw water turbidity is lower than 5 NTU during the fall and winter.

Preozonation for microflocculation. Tests performed using ozone doses of 0.4 to 0.9 mg/l upstream of chemical addition in the in-line and direct filtration modes improved turbidity removal by 50 percent. Ozonation also reduced the chemical doses by as much as 50 percent and lengthened the filter run times for in-line and direct filtration treatments. Regardless of the improved performance of filtration with preozonation, these treatments would be inadequate when raw water turbidity exceeds 12 NTU.

Media selection. Three media evaluations were performed to select physical properties of media and media bed depths for a multimedia gravity filtration system comprised of anthracite, sand, fine garnet, and coarse garnet. Side-by-side tests of two fine garnets showed that the material with superior grain size uniformity (1.7 versus 3.9) and larger effective size (0.26 mm versus 0.12 mm) provided more effective flow distribution and greater floc storage space. A similar test on two anthracite media produced similar results.

A third test was conducted with two filters that differed only in the depth of their anthracite beds. The filter with a 24-inch-deep bed had filter run times that were 20 percent longer than the 18-inch-deep bed. The rate of headloss in the deeper bed was also slower.

Design. A conceptual design for the new Hunter Creek Water Treatment Plant has been completed and final design is underway. From data gathered from the pilot study, the new plant will provide grit settlement, rapid mix, flocculation, lamellae plate clarification, and multimedia gravity filtration. The plant hydraulics will be flexible to allow in-line or direct filtration treatment when raw water characteristics are favorable.

Ten Mile Creek Water Treatment Plant, Helena, Montana

Helena, Montana, has relied on Ten Mile Creek for many years as its primary source of water supply. Overall, it is an excellent source from a water quality perspective...cool, clear, and soft. Up until now, the only treatment for this water was chlorination. However, increased awareness of the threat of giardiasis and forthcoming regulations with respect to lower turbidity requirements prompted the City to proceed with design of new treatment facilities for this plant.

CH2M HILL is designing a new 9-mgd water treatment plant for Helena, which will be our first full-scale application of Johnson/Microfloc Products' contact adsorption clarification technology. CH2M HILL has been involved in pilot plant evaluations of this process for more than 4 years at many other locations.

CH2M HILL was initially retained to perform pilot plant studies for this facility, and was subsequently asked to complete predesign and final design services. An extensive pilot testing program was completed with periodic testing over spring, summer, and winter periods. Due to the raw water's low solids content, extremely low alkinity, and variable pH and temperature, conventional treatment proved very difficult to control. In-line and direct filtration were tested extensively, but these processes did not produce consistent effluent quality, resistance to flow breakthrough, and/or satisfactory length of filter run under all conditions. The contact adsorption clarifier process proved to produce the most consistent and highest quality water when used in conjunction with an extra deep trimedia filter with coal, silica sand, and garnet media. This process consistently produced water with turbidity below 0.2 NTU even with operation at high rates and with water at temperatures as low as 1°C.

The final design will incorporate packaged contact adsorption clarifiers with a 4-foot-deep bed of bouyant plastic media operated in an upflow mode at rates up to 10 gpm/ft^2. The clarifiers will be washed by simultaneous upwash and air scour. Conventional downflow concrete gravity filters will use influent splitting weirs and feature a special mixed media filter bed design. Other features of the plant include low-cost sloping static influent screens, solids freezing/drying basins, and an operations building featuring a passive solar heating design. It is estimated that the contact adsorption clarifier system will result in construction cost savings on the order of $500,000 plus offer operational benefits including reduced coagulant dosage, ease of automation, reduced energy costs, and simplicity of operation.

Southwest Water Treatment Plant, Arlington, Texas

Construction is underway on a new water treatment and supply facility for the City of Arlington, Texas. The new Southwest Water Treatment Plant will have an initial nominal capacity of 25 mgd, designed for expansion in the future to as much as 125 mgd. CH2M HILL is providing complete engineering services for this facility, including predesign, final design, and complete services during construction. The plant will be conventional in some respects, providing tapered-energy flocculation, sedimentation, and filtration. There will be many unique features, however, included to provide a great deal of flexibility and reliability.

For example, the plant will be capable of operation in three basic modes to best meet varying water quality conditions: complete treatment, direct filtration with flocculation, and in-line filtration. The filtration system is designed to operate either in constant rate with influent splitting weirs or declining rate modes of operation, neither of which will require flow metering or complex rate control instrumentation.

The backwash system will also be very simple, requiring minimal equipment or energy. The filters will be backwashed directly with water from other filters in an interfilter mode with a raised, but adjustable, effluent weir that will control the backwash rate. Durability was a keynote of design. For example, only stainless steel is used in submerged applications in the plant. Chemical safety was another important design consideration. For example, the design includes a caustic scrubber system should there be an accidental release of chlorine gas.

INORGANICS CONTROL

Lake Texoma Regional Water Treatment Plant, Sherman, Texas

The Greater Texoma Utility Authority (GTUA) is a relatively new authority created to provide regional water and wastewater utility services in the greater Sherman area extending to the south shore of Lake Texoma. Lake Texoma is a man-made reservoir on the Red River, which is highly mineralized, partly as a result of brine discharges from upstream oil fields. The total dissolved solids of the lake averages greater than 1,000 mg/l with a recorded maximum in excess of 1,500. The hardness of the water typically exceeds 400 mg/l as $CaCO_3$, and the nutrient content is relatively high, at times resulting in profuse algae growth.

The primary water supply in the Sherman area has primarily been groundwater, which is generally of excellent quality. However, the local aquifer has reached its safe yield, and the GTUA is proceeding with development of a new regional water treatment facility to provide treated surface water from Lake Texoma. Initial conceptual planning for the project was based on conventional partial lime softening relying on blending with groundwater to produce an acceptable water from a mineral content. However, the blending concept over a large regional area proved to be very expensive, and the water would still be of marginal quality.

CH2M HILL proposed an alternative approach based on partial, split-stream demineralization of the product water from an optimized coagulation/filtration plant. This approach was found to offer substantially lower capital costs plus had the opportunity to produce a much superior water quality with fewer restrictions on regional implementation.

Conventional treatment. Pilot studies were first completed for the coagulation/filtration plant. Options that were evaluated included complete treatment with conventional flocculation and sedimentation basins, contact clarification, direct filtration, and in-line filtration. The recommended process includes complete treatment with a provision for seasonal in-line filtration with polymer treatment only to minimize operating expense and reduce solids disposal requirements. The preliminary design for this facility is a plant with an initial capacity of 10 mgd that is expandable to 40 mgd. Final design is underway.

Demineralization. GTUA and the City of Sherman are very concerned about water quality and the public's acceptance of the new surface water supply. Because of the high total dissolved solids (TDS) present in Lake Texoma, a demineralization system [RO or electrodialysis reversal (EDR)] will be included as part of the water treatment system. The demineralization system will minimize the differences between the surface water and groundwater sources and meet state drinking water standards.

The large temperature range of Lake Texoma water has major effects in the design of the demineralization facilities. Cooler temperatures not only result in lowering the efficiencies of the desalting process, but also negatively affect the solubilities of many compounds (such as barium sulfate). The maximum allowable recovery of the desalting system appears to be limited by the solubility of barium sulfate in the concentrate streams; however, scale inhibitors may help to alleviate this problem.

Because of limited membrane desalting experience with waters having the barium sulfate concentrations present at Lake Texoma, CH2M HILL recommended that onsite pilot testing (approximately 2,000 hours run time) be conducted to determine what recovery is possible. The work will be done using a scale inhibitor during the coldest time of the year. The pilot testing will also be used to quantify the fouling tendencies of the water from other substances such as dissolved organics, and will indicate if either an RO or an EDR system is technically more suitable for this particular application.

CH2M HILL is beginning the pilot testing this winter at the Red River Authority Water Treatment Plant located on Preston Peninsula at Lake Texoma. The RO process will be studied with CH2M HILL's 30-gpm pilot unit; Ionics, Inc., will provide the EDR pilot unit.

CH2M HILL has developed and procured a portable membrane pilot test unit capable of testing low pressure and ultralow pressure RO membranes as well as ultrafiltration (UF) membranes. The skid-mounted unit has a feed flow range from 13 to 30 gpm and is capable of product water recoveries up to 90 percent of the feed flow, depending on the application.

The test unit contains three 4-inch- and one 2.5-inch-diameter pressure vessel in a three-stage arrangement. Each pressure vessel is capable of holding six 40-inch-long spiral-wound RO or UF membrane elements. The membrane elements are not furnished with the pilot unit; they need to be selected and obtained for each specific project.

Feedwater pretreatment equipment with the unit consists of two chemical feed pumps and a cartridge filter. The pretreated water is pumped to the membranes with a multistage centrifugal feed pump rated at 240 psi at 30 gpm.

The pilot test unit is designed for manual control; however, automatic shutdown features are provided for low feed pump suction pressure, high membrane feed pressure, and low or high feed water pH.

Reverse Osmosis Water Treatment Plant, Englewood, Florida

CH2M HILL was retained to evaluate alternatives for increasing the water supply and treatment capacities for a water treatment plant in Englewood, Florida. Schemes that were evaluated included developing a new well field and constructing a new RO facility that would treat brackish groundwater.

An RO treatment plant was designed by CH2M HILL with provisions for staged 0.5-mgd expansions to an ultimate capacity of 3 mgd. The initial 0.5-mgd RO process train was commissioned in 1981. A later expansion in 1986, also designed and constructed by CH2M HILL, increased the RO plant capacity to 1.5 mgd.

The treatment system includes chemical addition for pH adjustment and scale control, filtration, high pressure pumping, degasification for removal of carbon dioxide and hydrogen sulfide, final pH adjustment for stability, and chlorination.

The RO treatment facility receives a brackish groundwater containing approximately 5,000 mg/l total dissolved solids, 2,500 mg/l chloride, and 1,300 mg/l total hardness, and produces a finished water containing less than 470 mg/l total dissolved solids, less than 250 mg/l chloride, and less than 80 mg/l total hardness. The RO facility product water is blended with finished water from an existing lime softening treatment plant. The waste reject is disposed of by discharge to a tidal waterway and/or to a new deep injection well designed by CH2M HILL.

In connection with the RO plant expansion, CH2M HILL developed and conducted an extensive membrane characterization program to identify the types of RO membranes that could be bid and to determine site-specific design criteria. Seven different types of RO membranes were tested. The RO membranes, test units, and test flow rates were provided by the manufacturers. Englewood Water District provided the pretreated feedwater, operated the units, and collected the test data. CH2M HILL provided technical assistance and developed the test program as well as analyzed the water samples, and reduced and analyzed the data.

WATER SOFTENING PLANTS

CH2M HILL continues to design many water softening plants. Major plants currently in some phase of design or construction are highlighted below.

Florida City Treatment Facility, Florida City, Florida

This will be a new 22-mgd plant designed for ease of expansion to 33 mgd. Solids contact, slurry recirculation reactor clarifiers will be used. Solids will be handled via drying basins.

Pompano Beach Water Treatment Plant, Pompano Beach, Florida

This will be a 40-mgd plant, expandable to 60 mgd, featuring reactor clarifiers. The filters will be designed to operate either in constant rate (influent splitting weirs) or declining rate modes.

Miami River/Ottowa Water Treatment Facilities, Dayton, Ohio

CH2M HILL has provided a wide range of engineering services for the City of Dayton over a period of nearly 20 years. Current projects include upgrading of the large rotary kiln at the Ottawa facility used for recalcining the dewatered lime sludge for both plants, and design of air stripping and powdered activated carbon systems for emergency spill protection at the Miami River Facility.

Water Treatment Plant No. 4, Austin, Texas

This will be a new 100-mgd plant expandable to 300 mgd. CH2M HILL is a major subconsultant on this project with responsibility for about 45 percent of the effort including a challenging raw water delivery system consisting of a 2.2-mile-long tunnel, a live lake tap, and a raw water pump station with vertical turbine pumps of 200-foot plus shaft length. Other responsibilities include the plant headworks and the chemical storage and feed facilities.

WASTEWATER RECLAMATION AND REUSE

Denver Potable Water Reuse Demonstration Plant, Denver, Colorado

The Denver Reuse project is a $29-million, 7-year project by the Denver Water Department to demonstrate that high quality water, equal to or better than Denver's current drinking water, can be produced safely and reliably from treated wastewater effluent. The U.S. EPA is also participating in this demonstration project by contributing approximately $7 million of the total cost.

Water treated by this facility will undergo 7 years of extensive testing for potential contaminating substances. Accompanying these tests will be an exhaustive program of health effects testing to document the safety of the product water.

The reuse plant includes the following processes in series from upstream to downstream: lime treatment and clarification, recarbonation, filtration, ammonia-sodium selective ion exchange, first-stage carbon adsorption, ozonation, second-stage carbon adsorption, RO, air stripping, and chlorine dioxide disinfection.

One mgd of unchlorinated secondary effluent from the Metropolitan Denver Sewage Disposal District No. 1 Treatment Plant is processed through first-stage carbon adsorption. Approximately 0.9 mgd of the first-stage carbon adsorption effluent is sent back to the treatment plant for industrial use. The processes downstream of first-stage carbon adsorption are designed to treat the remaining 0.1 mgd of first-stage carbon adsorption effluent. The plant was designed with this differential capacity to save money and yet still adequately provide data for future scale-up design.

The 7-year testing period began in the winter of 1983. The program includes five phases of treatment testing. In the first four phases, four different treatment trains will be studied to gather data on the most effective and reliable treatment. The fifth phase will include the treatment train found to be most effective from the previous four phases. Water produced during the fifth phase treatment sequence will be subjected to the health effects testing program designed to evaluate the toxicological safety of the reuse plant product water.

The second phase of testing was completed in the fall of 1986 and phase three is scheduled to commence early in 1987. Preliminary results indicate that the production of a reuse finished water equivalent to present Denver drinking water is certainly feasible with respect to engineering. However, the economics of the reuse treatment may delay its ability to compete with conventional water supplies for decades.

Tampa Water Resource Recovery Project, Tampa, Florida

The Tampa Reuse project is an innovative water supply plan that CH2M HILL developed for the City of Tampa and the West Coast Regional Water Supply Authority (WCRWSA) to help alleviate water supply shortages. The plan is particularly attractive to the region because it does not depend on groundwater, which serves as a barrier to saltwater intrusion in this coastal region, and it does not require the development of new water supplies inland that would compete with agricultural water demands in the region.

The plan provides additional treatment to an unchlorinated, denitrified effluent produced at the City of Tampa's Hookers Point Advanced Water Treatment (AWT) Plant. The supplemental treatment process must produce a water equal to or better than the existing Hillsborough River raw water supply. During water-short periods, the reuse production water will be discharged to a central pool where it will be used to augment the City's Hillsborough River raw water supply and/or will be drawn through adjacent aquifers by a well collection system that will transfer the reuse water to a new treatment plant operated by the WCRWSA.

Similar to the Denver Reuse Project, a pilot plant has been constructed to demonstrate that high quality water, equal to or better than Hillsborough River water, can be produced safely and reliably from the Hookers Point AWT effluent. However, the Tampa Reuse treatment objective is based on a raw water comparison, not a potable finished water comparison.

The 50-gpm reuse pilot plant contains four parallel treatment trains to allow simultaneous study of four processes. Each of the four treatment trains includes air stripping, lime treatment, two-stage recarbonation, and filtration. The treatment downstream of filtration differentiates the four treatment trains from one another. One includes disinfection, a second includes RO and disinfection, a third includes UF and disinfection, and a fourth includes carbon adsorption and disinfection.

The pilot study is scheduled to last 1 year in which one of the four processes or a blend of two of these four processes will be chosen for in-depth health effects testing to evaluate the toxicological properties of the reuse product water. The process selection will be based primarily on water quality comparisons with the baseline quality of the Hillsborough River water.

Construction of the pilot plant was completed in October 1986. The 1-year testing program, which includes approximately $2 million worth of analytical water quality monitoring and toxicological testing, is scheduled to commence in March 1987.

Abilene Water Reclamation Research Project, Abilene, Texas

The City of Abilene, like most West Texas cities, faces the continuing challenge of providing a sufficient potable water supply to meet its increasing demands. In planning for its 21st century water demands, the City of Abilene desires to continue pursuit of all potential water resources; from transporting water from distant reservoirs to developing unconventional water resources.

With respect to unconventional water resources, the City of Abilene has contracted CH2M HILL and the local firm of Freese and Nichols to investigate the possibility of expanding its water supply by augmenting their existing Lake Fort Phantom Hill surface water supply reservoir with reclaimed wastewater. To achieve public acceptance of this water reuse plan and meet water quality requirements sufficient to render this indirect potable reuse plan safe, a study has been recently approved, funded, and contracted.

The major objective of this study will be to determine acceptable water quality standards for the reclaimed wastewater as both a supplemental potable water supply and as a supplemental raw water supply to Lake Fort Phantom Hill. Available treatment technologies to achieve these two sets of standards will also be evaluated. In addition, a comprehensive water quality testing program will be implemented to develop baseline data on the existing Lake Fort Phantom Hill water quality. A public awareness program will also be initiated to educate the public on the subject of water reuse. Finally, a treatment train will be selected for development of a process demonstration plant.

After this preliminary study is completed in a scheduled 14-month time frame, the program will continue with design, construction, operation, and evaluation of a 0.5 to 1.0-mgd demonstration plant. Should the demonstration plant verify the safety and reliability of the reuse concept, a full-scale water plant would eventually be developed.

Upper Occoquan Sewage Authority (UOSA), Regional Water Reclamation Plant, Manassas, Virginia

The UOSA regional water reclamation plant was mandated by Virginia regulatory authorities in 1971 to replace 11 inadequate secondary treatment plants that were discharging their effluent into the Occoquan Reservoir, which serves as the principal water supply in Northern Virginia. The water quality of the reservoir steadily deteriorated during regional population growth during the 1960's. To reverse this deterioration and protect the regional raw water supply, the 15-mgd UOSA water reclamation plant was designed, constructed, and eventually put into operation in June 1978.

The plant includes processes to treat the wastewater to effluent quality limitations established by the State Water Control Board of the Commonwealth of Virginia. These water quality standards are among the most stringent in the United States.

The treatment train includes conventional primary and secondary activated sludge treatment processes, chemical clarification using lime and polymer, two-stage recarbonation with intermediate settling, flow equalization, multimedia filtration, granular activated carbon adsorption, ion exchange for ammonia removal, and chlorination.

Since UOSA's facilities have been in operation, a consistently high quality effluent has been produced. According to data collected by the Occoquan Watershed Monitoring Laboratory, the plant began having a positive effect on the water quality in Bull Run, a tributary to the reservoir, within months after startup. The UOSA project has provided a means of protecting the reservoir from point-source pollution while producing a significant supply of reclaimed wastewater for reuse.

Because of excessive flow from infiltration and inflow as well as rapid growth in the service area, the UOSA plant is presently gearing up for a capacity expansion from 15 to 22.5 mgd. In addition, the secondary activated sludge system will begin operating in the carbon oxidation-nitrification mode year-round to remove ammonia. During the plant expansion, selector technology will be incorporated into the secondary system to control filamentous sludge bulking that inhibits nitrification.

SUMMARY

This paper examines the emerging water treatment technologies in the U.S. which will have application in the 21st century in both industrialized and developing countries. Some of the technologies discussed are in the pilot stage of development, others are under construction and others have been placed into operations. Water treatment technologies for the year 2000 and beyond which have been discussed are:

- Groundwater activated carbon adsorption
- Powdered activated carbon adsorption
- Floc-blanket clarification
- Lamella plate clarification
- Preozonation for microflocculation
- Airstripping technologies
- Reverse osmosis demineralization
- Electrodialysis reversal demineralization
- Constant head versus declining rate filtration
- Potable water reuse technologies
- Mobile pilot treatment plant usage

One of the motivating factors that will be pushing these new technologies in the year 2000 and beyond is the ability to monitor for new water contaminants. For many years, the quality of a potable water supply has been judged by its clarity/turbidity level and the presence or absence of coliform bacteria. Both tests were used as a surrogate to other testing procedures to predict the safety of a public water supply. We now know that many other inorganic and organic contaminants and microbiological organisms have found their way into the water supplies of all countries. During the last 10 years, gas chromatograph/mass spectroscopy technology has been developed to a state that many organic compounds can be measured in the parts per billion range. In the next 20 years, I am sure new developments will continue to be made which will directly affect the water treatment technologies of the 21st century. While the coliform tests have been an excellent microbiological screening procedure, the test does not indicate the presence of Giardia or several newly discovered microbiological pathogens.

One of the most frustrating by-products of our new analytical monitoring technology is "how clean is clean." Because we can measure a contaminant in the parts per billion range, does this necessarily justify its being removed from drinking water supplies? The science of toxicology has not kept up with our monitoring capabilities. Certainly one of the largest challenges to be met in the 21st century will be to better understand the public health consequences and the risk assessment related to parts per billion and trillion range contaminants in our water supply systems.

The subject of technology transfer to developing nations is indeed a subject that will challenge the water supply field in the next century. The World Health Organization attributes 15 million deaths per year to waterborne diseases or to the lack of water. The failure of the United Nations World Water Decade--the decade of the eighties--should be sufficient warning to all of us that the problems of safe, adequate water supply for nearly 5 billion inhabitants of the earth is a major problem which will continue to grow until mankind overcomes the social-political and economic problems associated with safe drinking water. This paper suggests that the water treatment technologies are available now to accomplish the goal of the United Nations--that is to provide adequate safe potable water to all the people of the earth.

SESSION 8

SEANCE 8

Chairman / Président: Prof. Dr. K. OEHLER

- New Aspects of Microbiological and Chemical Treatment of Drinking Water in the Aquifer

  Aspects Nouveaux du traitement microbiologique et chemique de l'eau potable dans la zone aquifère

  U. Rott

- The Virology of Water Supply in the Future

  Nouvelles Perspectives dans la Virologie des Eaux d'Approvisionnement

  J. Perramon, F. Ribas

Discussion

NEW ASPECTS OF MICROBIOLOGICAL AND CHEMICAL TREATMENT OF DRINKING WATER IN THE AQUIFER

U. Rott
Zweckverband Ostholstein
Strandallee 112-114
D-2408 Timmendorfer Strand, F.R.G.

ABSTRACT

Microbiological and chemical oxidation and reduction reactions in the aquifer influence the concentration of iron, manganese, nitrate, ammonia and organic substances in the groundwater. The so called subterranean groundwater treatment is based on a change of the redoxpotential caused by the recharging of oxygenated water into the underground. This method has been applied in several European and in some tropical countries as well. The following microbiological, chemical and physical mechanisms may effect the removal of iron, manganese and ammonia from groundwater and thus substitute water works treatment plants. Under anaerobic conditions the removal of nitrate and organic substances is possible too.

The transport and expansion of oxygenated water can be measured through experiments or by using a mathematical model, which is based on a diffusion-convection equation combined with a sorption term.
Calculations as well as field tests show that all of the treated water pumped out of a well after oxygenated water had been recharged into it did not come into contact with oxygenated water. The treatment success can be explained by storage phenomena in the oxidated zone. It is thought that adsorption and oxidation at extraccelular slime substances are the main treatment mechanisms.

KEYWORDS

Groundwater treatment in the aquifer; iron removal; manganese removal; nitrification; denitrification; oxidation; redoxpotential; iron bacteria; manganese bacteria.

INTRODUCTION

The quality of groundwater depends on its content of soluble and insoluble substances. The concentration of several substances in groundwater e.g. iron and manganese varies with oxidation and reduction reactions. The redoxpotential indicates the oxidation grade of a solution containing substances like iron or manganese. A change in the solution in oxidative direction is measured by raising redoxpotential due to the electro-chemical definition of oxidation as delivery of electrons. The redoxpotential decreases when the oxygen content of perculating water is consumed by decomposition of organic matter or pollutions.

The concentration of iron or manganese in groundwater can rise considerably with decreasing redoxpotential without any change in pH-value. This characteristic was first shown in stability field diagrams by Hem. The concentration of iron in groundwater can decrease by a factor of 10^4 by raising the redoxpotential 220 mV.

Recharging of oxygenated water into the aquifer, thus raising the redoxpotential of the groundwater can under certain conditions result in complete removal of iron and manganese from the underground water. Nitrification of ammonia may result from the aeration too.

Biological denitrification (heterotrophic type) however is obtained under anaerobic conditions if assimilable carbon is available. Autotrophic denitrification is based on the oxidation of anorganic substances as FeS, Fe^{++} or H_2.

TRANSPORT OF OXYGEN INTO THE AQUIFER

The oxygen cannot be transported into the aquifer in the gaseous form. The oxygen should be solved in water. Oxygenated recharge water can be taken from wells, from a water supply system or from reservoirs. In most cases the recharge water is saturated with oxygen from the air. The oxygenated water should be recharged into the aquifer through discharge wells. Thus the recharged water is distributed into the same layers of the aquifer and the same pores which are pumped afterward as explained below. At least two wells are necessary for alternative recharge and pumping.

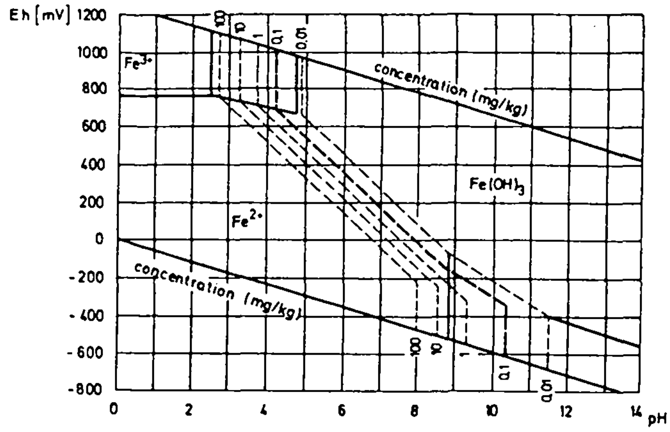

Fig. 1. Eh-pH-diagram of iron in water (Hem)

If more than two wells are available a part of the pumped water can be served for supply continously and an other part can be abstracted, saturated with oxygen, and recharged in one of the wells again.

Table 1 Some microbiological processes in groundwater treatment

	nitrate	ammonia	organic substances	iron	manganese
process	denitrification	nitrification	oxidation denitrification	oxidation	oxidation
milieu	anaerobic	aerobic	aerobic anaerobic	aerobic	aerobic
bacteria	Pseudomonas Denitribacillus Micrococcus	Nitrobacter Nitrosomonas		Gallionella Chlamydob.. Siderocapsa..	Sphaerotilus Pseudomonas..
reagent	organic subst. hydrogen	oxygen	oxygen nitrate..	oxygen	oxygen
product	N_2	NO_3	CO_2, H_2O	Fe(III)	Mn(IV)

In the context of design of a plant for subterranean groundwater treatment the movement of oxidizing agents together with their reactions with other substances as organic matter and specially iron and manganese within the porous medium must be considered. The transport of oxygen in groundwater depends on the velocity of the groundwater and of the recharged water and on dispersion and sorption processes as well.

The transport and expansion of oxygenated water can be measured through experiments or by using a mathematical model, as was found by Rott, Boochs and Barovic (1978) and Aleksejew and Kommunar (1983). The model is based on a diffusion-convection equation combined with a sorption term like the following:

$$\frac{\delta c}{\delta t} = \frac{1}{r} \cdot \frac{\delta}{\delta r} (\alpha \cdot u \cdot \frac{r \delta c}{\delta r} - \frac{1 \delta}{r \delta r} (u \cdot r \cdot c) - \frac{1}{\varepsilon} \frac{\delta s}{\delta t} \qquad (1)$$

$$\frac{\delta s}{\delta t} = k_1 \cdot c - k_2 \cdot s \qquad (2)$$

$c\ (r, t)$ = concentration of dissolved material

$s\ (r, t)$ = concentration of sorbed material

r = radial distance from the well

α = longitudinal dispersivity

u = mean pore volocity

ε = pore volume

k_1, k_2 = rate coefficients

The rate of sorption s/ t depends on the type of soil, the substances, and the concentration of the species in the dissolved as well as the sorbed phase. The simplest calculation leads to equation 2 assuming that the change of concentration is equal to the difference between the rates of adsorption and desorption. Supposing equilibrium between liquid and solid phase, the concentration of sorbed material depends on the concentration of the solute only. The relation between the dissolved state and solid state may be approximated by a linear, Freundlich or langmuir isotherm.

The reaction between oxygen and iron or manganese is simplified to the sorption of oxygen and soluble iron or manganese. Taking some more assumptions into account the concentration of oxygen and iron in the aquifer can be calculated according to the resolution of the mentioned equations. The mathematical model produces under horizontal and radial symmetrical stream conditions concentration profiles of the oxygen in oxygenated water that had been recharged into a well and of soluted iron in the aquifer as shown in Fig. 2.

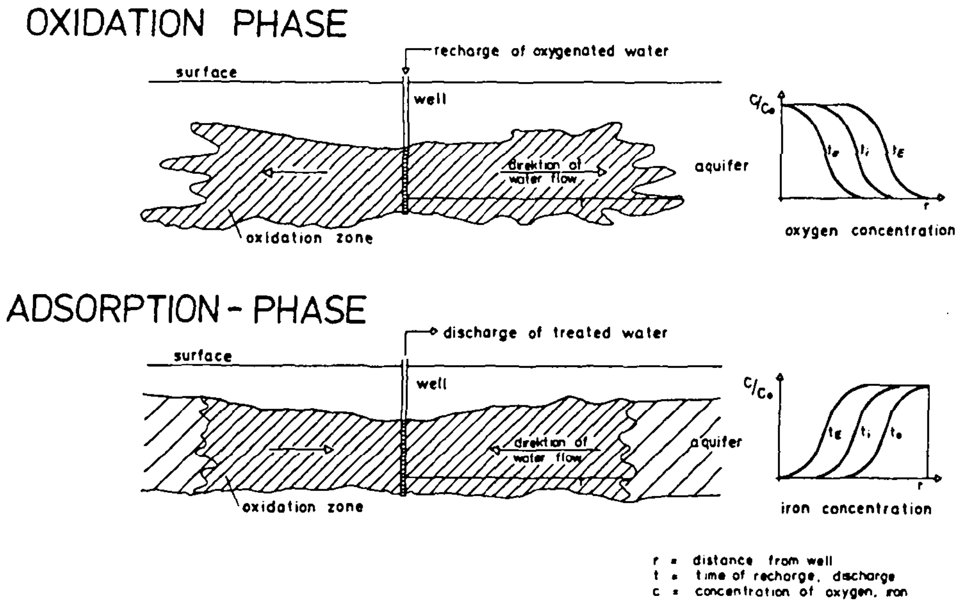

Fig. 2 Concentration profiles during oxidation and adsorption

This calculation as well as a lot of field tests show that all of the iron-free water pumped out of the well after oxygenated water has been recharged into it did not come into contact with the oxygenated water. The volume of pumped water is bigger than the volume of pores in the oxidation zone shown in Fig. 2.

The amount of iron-free water that can be pumped out after each separate but equal recharge of the oxygenated water increases with time. This result differs from what we already know about iron and manganese removal mechanisms in water works filters. Rott (1981) has shown that storage phenomena provides a possible explanation.

ADSORPTION AND OXIDATION

The amount of iron and manganese, which is dissolved in natural groundwater, depends on the concentration of oxygen, carbonic acid and carbonate in the groundwater. By decomposition of organic matter in the soil the oxygen of the percolating rain-water is used up and carbon dioxide arrives and is dissolved in the percolating water.

Under reductive conditions considerable amounts of iron and manganese are dissolved and transported into the aquifer. Conversely iron and manganese containing groundwater may take up oxygen in aerated bottom layers. The change of redoxpotential in this way decreases the solubility of iron and manganese and causes precipitation of iron and manganese hydroxydes.
A change in the solubility of iron and manganese by oxidation reactions is the basis of all processes of iron and manganese removal and of subterranean groundwater treatment as well. In water works treatment three stages for iron and manganese removal are known:

1. Oxidation of iron(II) to iron(III) and of manganese(II) to manganese(IV)
2. Flocculation of iron and manganese hydroxides

3. Separation of flocs by means of filters or other equipment.

Under natural conditions oxygen from the air is used as oxidizing agent. In water works treatment chemicals like potassium permanganate ($KMnO_4$), chlorine dioxide (ClO_2), and ozone (O_3) are used as well. The oxidation of iron e.g. is summarized in the following equation:

$$2\ Fe^{++} + 1/2\ O_2 + (x + 2)\ H_2O = Fe_2O_3 \cdot xH_2O + 4\ H^+$$

The velocity of the oxidation reactions depends on the pH-value of the solution and is accelerated by contact with iron or manganese hydroxides in a catalytic manner. Therefore a porous medium in which the oxidation of iron and manganese expires in presence of iron and manganese hydroxides at the same time, is the ideal place for iron and manganese oxidation. Compared with iron the bivalent manganese ($Mn(O_3)_2$, $MnSO_4$) is more resistant against oxidation by oxygen from air and thus catalytical influences are important to accelerate the velocity of the oxidation of manganese.

In the aquifer the so called "adsorptive -catalytic" oxidation of manganese is possible without chemicals for raising of the pH-value ore as oxidizing agent. In this case the already precipitated manganese hydroxide (manganese dioxide) adsorbs manganese(II). By catalytical reaction the oxygen dissolved in the groundwater allows the oxidation of the manganese with sufficient velocity. It is necessary to complete the removal of iron before starting the catalytic removal of manganese. Otherwise deposits of iron would cover the catalytically efficient manganese dioxide.

Freshly precipitated iron hydroxides are known to adsorb ions too. Adsorptive-catalytic oxidation thus is also possible for iron. In a first step iron(II) is adsorbed on iron(III)hydroxides. In the second step oxygen e.g. by aerated water is added and starts to oxidize the adsorbed iron. Thus new iron hydroxide is created and simultaneously new adsorption space is available to adsorb iron(II).

With each recharge of aerated water into a well an oxidized zone around the well is created, what was found by Eichhorn (1983) too. In the first step the oxygen and iron dissolved in the groundwater react with each other and unsoluble ferric hydroxides start to cover the solid material of the underground. During pumping this layer of ferric hydroxides adsorbs soluble iron(II) from the untreated groundwater until its adsorption capacity is exhausted. During the next step in which oxygenated water is recharged into the aquifer the oxygen reacts with the adsorbed iron(II) and creates new ferric hydroxides and thus new adsorption capacity. After this recharging step an additional pumping step can follow. The untreated groundwater then passes through the oxidated zone again, and soluble iron is adsorbed on the ferric hydroxide layers and so on (Fig. 3). The reaction velocity is high enough due to autocatalytic acceleration even though the pH-value may be low. Van Beek (1979) has developed a similar explanation.

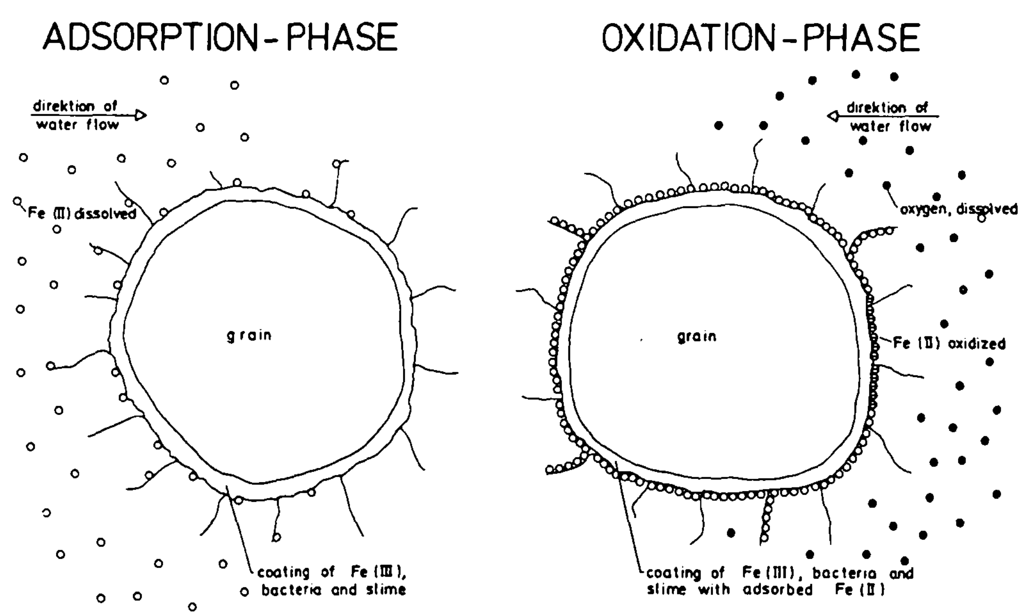

Fig. 3. Adsorption model

The oxidated zone should be large enough, so that iron removal can take place in the outer part of the oxidated zone. Manganese removal takes place in the inner part of the oxidated zone. The adsorption space for manganese must not be covered by iron hydroxide deposits.

The quantity and velocity of the recharged oxygenated water has to be calculated exactly in order to create an oxidation zone, which allows for the removal of both iron and manganese. Flocculation and precipitation of other substances soluted in the groundwater is possible combined with the oxidation of iron in groundwater.

BIOLOGICAL OXIDATION OF IRON AND MANGANESE

Iron and manganese bacteria are found in nearly all aquifers. The amount of either aerobic or anaerobic bacteria does not depend on the depth of the aquifer. The purification of groundwater in the aquifer works in the same way as biologically active rapid sand filters. High oxidation rates are achieved in direct contact with biological structures (extracellular polymeric slime substances). The biological metal ion oxidation was found to be one of the following processes (Czekalla, Mevius and Hanert; 1985):

Gallionella iron oxidation
Leptothrix ochracea iron oxidation
Toxothrix trichogenes iron oxidation
Leptothrix lopholea manganese oxidation
Metallogenium manganese oxidation
Hyphomicrobium manganese oxidation
Siderocapsa manganese oxidation
Siderocystis manganese oxidation

Above the pH-value of 4 and the EH-value of + 220 mV oxidation of iron by soluted oxygen is possible. The velocity of oxidation increases with rising pH-value. Below pH-value of 4 no remarkable oxidation of iron appears. Autotrophic iron bacteria however oxidize iron(II) to iron(III) above pH-values of 0,5 and gain energy from this process. As mentioned iron(II) due to the redoxpotential and to the oxygen content in the groundwater is soluted and movable under anaerobic conditions. After additon of oxygen and raising of the pH-value iron is oxidized by means of chemical reaction and precipitated. Aerobic bacteria are able to gain energy, only if they anticipate the chemical oxidation. Aerobic bacteria have to use the iron(II) already at the boundary between aerobic and anaerobic conditions.

It is not yet known whether iron precipitating bacteria as Gallionella, Chlamydobacteria and Siderocapsa should be regarded as autotrophic or mixotrophic. Some iron bacteria are able to precipitate iron(III) on their cell-surface and to use iron in the chemical combination of FeS, FeS_2 and FeO as well. Under laboratory experiment conditions this was shown with Gallionella and Chlamydo bacteria while organic matter was present.

If iron(II) appears in organic combination the above mentioned stability field diagrams are no longer valid for calculation of the solubility of iron. The natural, organic ingredients of the iron(II) complexes are possibly resistant against bacteria under anaerobic conditions. Specially humic acids are known to be hardly decomposed and should be treated as stable chelating agents.

Under aerobic conditions produced by addition of aerated water subterranean groundwater treatment however may enable bacterial oxidation of iron(II) complexes and precipitation of iron(III). The bacteria apparently are able to use iron in organic combination or the organic compound, or the iron(II) which is freed from the organic complex as well. In groundwater containing iron(II) in organic combination Gallionella, Chlamydo bacteria and Siderocapsa were observed.

Soluble manganes(II) arises under higher pH and EH conditions compared with iron. Manganese(IV) is reduced already at the EH-value + 300 mV and pH values between 6 and 7. On the other hand the chemical oxidation of manganese(II) with oxygen from the air as oxidizing agent takes place in the range of pH 8 - 8,5. It is supposed that manganese(IV), which is found under low pH and EH conditions, was oxidized by microbiological reaction. Some bacteria e.g. Sphaerotilus discophorus are able to oxidize manganese and to precipitate it on their sheaths. It is not known wheather these bacteria are able to gain energy from the reaction Mn(II) to Mn(IV) as well.

Some special bacteria however are exclusively dependent on the oxidation of manganese. At last the bacteria Pseudomonas are known to oxidize manganese below the pH-value of 7. Chemical and microbilogical oxidations take place simultaneously or under different environmental conditions after addition of oxygenated water into the oxidated zone. It is possible that the chmemical and microbiological oxidations start in different places in the oxidated zone.

NITRIFICATION AND DENITRIFICATION IN THE AQUIFER

The recharging of oxygenated water into the aquifer may cause biological nitrification of ammonia into nitrate. The nitrification covers two successive reactions (Fig. 4). The first reaction is the formation of nitrites by bacteria: Nitrosomonas, Nitrosocystis etc. The second reaction is the formation of nitrates by bacteria of the genera: Nitrobacter, Nitrocystis etc. All these bacteria are autotrophic and strictly aerobic. They use the energy produced by the oxidation of ammonia and of nitrites to reduce inorganic carbon, originating from carbon dioxide or carbonates.

In groundwater the denitrification is regarded as the dissimilative reduction of nitrates or the reduction of nitrates by respiration (Fig. 4). If heterotrophic bacteria reduce nitrates and nitrites to nitrogen gas this process requires the presence of carbonaceus organic matter. Autotrophic bacterial denitrification has been carried out with hydrogen gas (Seyfried and Olthoff, 1986). Denitrification bacteria need an anaerobic milieu. Bacteria are Pseudomonas, Denitribacillus, Micrococcus etc. Due to different milieu conditions nitrification and denitrification have to be two separated treatment steps in different zones of the aquifer.

Biological nitrification and denitrification in the aquifer has achieved new importance since the World Health Organisation's standard for nitrate was lowered to 50 mg NO3/l.

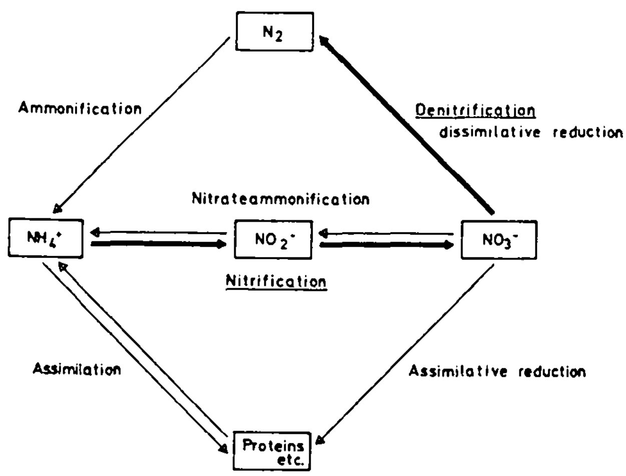

Fig. 4. Biological nitrogen cycle

TREATMENT TECHNOLOGY

Microbiological chemical oxidation processes, which are necessary for the removal of iron, manganese and ammonia from groundwater, are released by addition of oxygen into the aquifer as mentioned above. It is not possible to transport oxygen in the gaseous condition in horizontal direktion in groundwater. Therefore it is necessary to dissolve oxygen in recharge water and to distribute the oxygen together with the recharge water in the aquifer.

For the transport of the recharge water into the aquifer either special recharge wells or production wells are used. The recharge by special recharge wells can be adapted to local conditions depending on the gradient of groundwater, the direction of groundwater flow, and the groundwater quality.

Continous pumping from the production wells is not possible, even if recharge wells are available. Pumping from the production wells during recharge of oxygenated water would cause a direction of groundwater flow straight to the production well. An equal distribution of recharge water in the oxygenated zone would be impossible. The production well in each case must not pump during recharge of oxygenated water into the attached oxygenated zone.

Recharge of the oxygenated water by means of the production well ensures, that the recharge water is distributed exactly into the same layers of the aquifer which are used during pumping. Deviations in the geological profiles combined with recharge through special recharge wells may lead to interruptions in the oxygenated zone and may therefore cause trouble in the subterranean groundwater protection.

The iron and manganese concentrations recommended for drinking water are attained after stabilisation of the oxidated zone around the wells within a maturing time of some days up to several months. The maturing time depends on the chemical composition of the groundwater to be treated. PH-value, hardness and carbon dioxide concentration are important and the proportion of the substances to be removed as well.

Sufficient success of subterranean groundwater treatment is realized with amonts of recharge water, which are not bigger than 5 to 30 % of the pumped water.

NECESSARY FUTURE ACTIONS

Microbiological treatment of drinking water in the aquifer, which is a new kind of biotechnology, will achieve more and more importance for a safe drinking water supply beyond the year 2000.

If there is any choice for supplying the public with drinking water between various possible sources as there are underground water, surface water from rivers or surface water from lakes, the supply from underground water should be prefered. Though underground water is better protected against pollutions as surface water account must be taken to the circumstances which may arise in the near future.

One problem of the future is the nitrate problem arising from an increasing use of agricultural fertilizers and of waste waters of human and animal origin. This problem may arise in high industrilised countries as well as in developing countries too. The above described denitrification biotechnology is an instrument which can be developed to an uncomplicated and not expensive technology to solve the future nitrate problems specially in the countries of the third world too.

On the other hand close regard should be given to the problem of organic pollutions arising from phenols, hydrocarbons, detergents, pesticides and plant health products. Already today in some surface near groundwaters concentrations of these substances are found, which can not be tolerated. If the input of these substances will not decrease, the organic pollution of groundwater will be another problem of the future.

Additional investigations will be necessary to find out whether the described biotechnologies are able to degradable these organic substances. In case there will be no sufficient technology in the next few years the use of those substances which are not biodegradable should not longer be allowed.

In conclusion one main future action in the water supply profession is to develop biotechnologies which allow to protect the underground water against the mentioned pollutions. This action in any case should be accompanied by the general challenge to minimize all immissions of organic pollutions to the ground and to the groundwater now and in the future.

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NOUVELLES PERSPECTIVES DANS LA VIROLOGIE DES EAUX D'APPROVISIONNEMENT

F. Ribas et J. Perramón

Societé Générale des Eaux de Barcelone

P. St. Joan, 39. 08009 Barcelona

ABSTRACT

This publication revises the improvement made in the field of the Water Virology Research over the last twenty years, comparing the general knowledge with our own practical experience on different methods of concentration of Enteroviruses from water and sludge (of several kinds), and our knowledge of viral and bacterial pollution in a river bassin (including groundwater) which supplies drinking water to almost the whole Metropolitan Area of Barcelona (Catalonia, Spain). We also discuss the removal of viruses by the fluvial - water treatment and the application of the statistic analysis for the interpretation of results. Likewise, future perspectives will be considered, with broader research possibilities of Rotavirus, the Hepatitis A virus (HAV) and other viruses related to recent and future epidemical outgrowths. Above mentioned items - are not only treated in a general sense but we also hope through our own needs for the correct management of the Water Supply to be serving any requirements of other institutions.

KEYWORDS

Viral concentration; Enterovirus; Rotavirus; Llobregat river; groundwater; fecal pollution; flocculation - sludge; chlorination; activated carbon filtration; statistic analysis.

INTRODUCCTION

Le commencement d'une préoccupation importante en ce qui concerne le thème de la transmission des virus entériques à travers le cycle de l'eau remonte à la décade des années soixante. Le problème principal qui se pose, en étudiant ces virus, en comparaison avec les bactéries d'origine fécal, est le faible nombre qu'ils éliminent des fèces humaines, ce qui oblige à soumettre, même les eaux contaminées, à un processus plus ou moins complexe de concentration si on désire effectuer une analyse virologique afin de déterminer le risque sanitaire de celles-ci.

Les pratiques analytiques les plus simples et reproduisibles sont celles qui permettent de mettre en contact un échantillon le plus représentatif possible avec le reactif le plus efficace pour obtenir une lecture rapide sans que se présentent des interférences. Dans le cas des virus, un échantillon même représentatif n'est pas d'habitude homogène et il doit expérimenter une concentration, laquelle représente des problèmes d'adsorption et l'élution des virus à un support. Une fois concentré, l'échantillon doit être libéré des substances interférentes (en essayant, ce qui n'est pas toujours possible, de ne pas se liberer des particules viriques) qui pourraient provoquer des effects toxiques (substances chimiques) ou contaminants (microorganismes) dans le réactif, qui est la culture cellulaire. Finalement, ce réactif, cher et d'entretien complexe, n'est pas sensible de la même manière à tous les virus et réagit de façon tres lente, car l'effet cytopatique qui permet d'assigner un résultat à l'analyse met plusieurs jours à être lu.

Toutes ces difficultés méthodologiques, qui compliquent en grande mesure n'importe quelle tentative de comparaison entre les résultats obtenues par différents auteurs avec différentes eaux, représentent peut être le motif principal pour lequel l'avance énorme effectuée dans le domaine de la virologie des eaux durant les dernières années ne se soit pas cristallisée par l'élaboration de normes ou de recommendations sanitaires au niveau international à propos de la présence de virus, de manière comparable à ce qu'il existe pour les bactéries et les substamces dangeureuses. Les déjà vielles recommendations de la O.M.S. (1972) sur l'absence de virus par 10 l. d'eau épurée sont déjà passées au terrain de l'anecdote historique, car il n'y a pas d'accord unanime sur le risque sanitaire associé à la présence de virus dans l'eau, risque épidemiologique dans beaucoup de cas très difficile à démontrer, bien qu'il existe, étant caché par des autres voies épidemiologiques de transmission plus évidentes.

Notre apport à ce thème s'est limité depuis 1981 au domaine de la méthodologie pour la concentration de virus. Dans ce travail nous avons essayé d'expliquer nos expériences en méthodes de concentration, l'étude d'un bassin fluvial et de l'approvisionnement d'une réalité urbaine de trois millons d'habitants et nos propres perspectives pour le futur, dans un contexte global de la virologie environnementale et des eaux face à la décade des années quatre-vingt-dix.

MISE AU POINT DES METHODES

Dans le contexte d'un plan d'étude des virus entériques en rapport a l'approvisionnement d'eaux à Barcelone, la Société Générale des Eaux de Barcelona (S.G.A.B.) et le Département de Microbiologie de la Faculté de Biologie (Université de Barcelone), collaborent étroitement à la mise au point de méthodes adaptées à la detection des virus entériques dans des eaux, sédiments et interphases de divers types. Les titrages des virus ont toujours lieu dans le Département de Microbiologie.

Adsorption/Elution dans la Poudre de Verre

La méthode de concentration utilisée initialement pour les eaux a été celle d'adsorption/élution sur la poudre de verre (Sarrette, Danglot et Vilaginès, 1977; Schwartzbrod et Lucena, 1978) avec quelques modifications (Ribas, Huguet et Perramón, 1986). En résumé, la modification la plus importante a été la mise au point d'un virocencentreur de plus grandes dimensions (grand appareil) qui permet de passer un volume sensiblement plus grand d'eau par unité de temps (500 l./h. face à 80 l./h.) avec une éfficacité non inférieure à celle du petit appareil de Schwartzbrod et Lucena (1978).

L'efficacité du système a été mis en évidence avec des expériences de concentrations parallèles de la même eau fluviale avec les deux appareils (50 l. avec le plus petit et des volumes croissants avec le grand) (Tableau 1) et en observant la récupération et les pourcentages de positivité de diverses doses de virus ajoutées à différents volumes d'eau épurée dechlorée (Tableau 2).

Dans l'eau de surface, on observe une efficacité globale en ce qui concerne les pourcentages de positivité clairement plus élevés avec le grand appareil (même si c'est en utilisant une quantité triple de poudre de verre, 450 face à 150 g.) en traitant des volumes plus grands d'eau, mais la détection d'un nombre d'unités viriques par unité de volume clairement inférieure.

La recupération des virus Polio I vaccinal LSc2ab ajoutés a l'eau épurée déchlorée a été étudiée au cours de 40 essais pendant lesquels on combine différentes doses (10) et différents volumes (4), de manière à répéter plusieurs fois (de 1 à 4) les mêmes (13) concentrations (UFC/l.) des virus. Les quantités de virus, les volumes, et, par conséquence, les UFC/l., varient dans un facteur $\sqrt{10}$. Les récupérations moyennes se calculent en agroupant les divers essais selon trois critères: UFC ajoutées, litres traités, et UFC/l. concentrées.

On observe à grand trait une nette tendance à obtenir de plus grands pourcentages de récupération moyenne à plus de UFC et UFC/l. ajoutées et à moins de litres traités. Néanmoins, le pourcentage d'essais positifs (globalement 67 % et aussi supérieur à plus UFC et UFC/l.) ne garde pas un comportement parallèle à la recupération dans le cas du volume de prélèvement.

Dans la Fig. 1 sont représentées les droites de régression de UFC, UFC/l. et des litres en fonction des pourcentages de récuperation et de positivité. On observe des coefficients de correlation assez élevés sur 5 des 6 droites calculées, étant précisement l'exception celle qui correspond à la positivité en fonction des volumes. Il est intéressant de constater que la droite récupération/volume coupe l'axe des x sur les 3127 l., volume pour lequel en théorie la recupération serait nulle pour comblement complet des sites d'adsorption des virus à la poudre de verre.

Comme l'expérience réelle démontre dans la concentration de nos eaux, le concepte de comblement se réfère à la capacité d'adsorption des virus de la part de la poudre de verre, parce qu'en théorie on peut traiter, sans problèmes physiques, un nombre illimité de litres d'eau de n'importe quelle qualité. Les probables problèmes se présenteraient au moment de l'élution, de la décontamination et détoxification ou, peut-être, de -

TABLEAU 1 Concentrations parallèles Appareil Grand/Appareil Petit (1981-1986)

	Petit appareil			Grand appareil		
l. petit ap./ l. grand ap.	Virus/50 l. ($\bar{x}$ + s)	+/total	% +	Virus/50 l. ($\bar{x}$ + s)	+/total	% +
50/50	6.3 ± 13.6	10/20	50	15.7 ± 34.8	14/20	70
50/100	19.0 ± 73.7	7/20	35	25.4 ± 49.8	16/20	80
50/200	7.3 ± 20.1	9/20	45	4.2 ± 12.9	13/20	65
50/300	7.9 ± 17.2	8/20	40	1.7 ± 4.5	8/20	40
50/400	18.7 ± 73.8	8/20	40	2.1 ± 6.4	13/20	65
	11.0 ± 48.8	42/100	42		64/100	64

TABLEAU 2 Récupération Moyenne et Positivité

Selon UFC ajoutées			Selon litres utilisés			Selon UFC/l. ajoutées		
UFC	% rec.	% +	l.	% rec.	% +	UFC/l.	% rec.	% +
1000000	34.8	100	31.6	51.4	80	31600	68.0	100
316000	57.4	100	100	37.6	60	1000	32.4	100
100000	38.3	100	316	10.4	50	3160	19.8	100
31600	21.2	50	1000	20.4	80	1000	19.8	75
10000	42.3	100				316	24.2	75
3160	23.6	50				100	15.5	100
1000	18.8	50				31.6	7.7	50
316	6.3	33				10	28.0	75
100	2.0	25				3.16	15.8	33
31.6	3.6	25				1	10.7	50
						0.316	0.0	0
						0.1	6.1	50
						0.0316	0.0	0

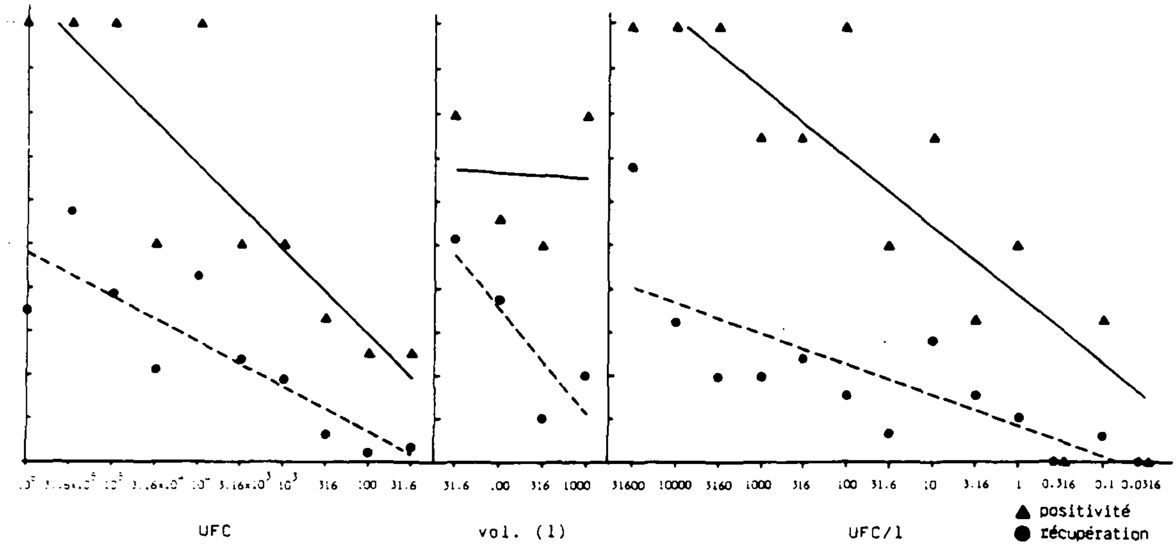

Fig. 1. *Récupération et positivité en fonction de UFC, volume et UFC/l.*

l'inoculation des concentrés dans la culture cellulaire.

Adsorption/Elution sur Microfibre de Verre

La concentration de virus sur un support de microfibre de verre a été seulement pris comme système alternatif à la poudre de verre pour les eaux déjà traitées et de basse turbidité. Malgré cela, bien qu'il soit possible quelquefois de traiter plus de 2000 l., les filtres ont été comblés dans beaucoup de cas avec seulement quelques centaines de litres.

Le terme comblement dans ce cas renvoie à l'occupation physique des pores du filtre par des particules en suspension. De cette façon, bien que l'adsorption de virus ait lieu dans la microfibre par les mêmes mécanismes électrostatiques que pour la poudre de verre, il se produit un mécanisme additionnel de rétention par filtration de possibles virus adsorbés sur matériel particulé.

Les premières expériences donnèrent de meilleurs résultats avec l'élution des virus avec de la glycine à pH 10.5 en broyant les cartouches filtrantes (Rolland et Block, 1980) qu'en recirculant beef-extract 3 % à ph 9.5 (58 % face à 41 % comme moyenne de trois séries d'expériences). On a utilisé indistinctement les cartouches filtrantes Balston C 100-12, les Whatman 12-80 et les Finite Filter 8G 10-025, tous de 8 µm. de pore.

En essayant un volume fixe de 50 l. d'eau épurée déchlorée à laquelle on ajoute différents niveaux de virus Polio 1 vaccinal LSc2ab, on a observé que des concentrations de 2 UFC/l. sont détectées sur 3 de 4 essais, tandis que des concentrations de 200 UFC/l. et de 20000 UFC/l. son détectées 100 % des fois avec récuperations moyennes respectives de 52 % et 49 %.

Appareil Portatif Polyvalent

Dans les considérations relatives à la concentration de grands volumes (plus de 500 l.) d'eau traitée, nous n'avons pas fait allusion au problème que représente le transport des échantillons. Il est évident que si on désire pallier ce problème, la solution la plus simple est d'utiliser un appareil concentrateur sur le terrain qui dosifie les réactifs ver l'échantillon au fur et à mesure qu'on le prend.

C'est pour cela que, durant les dernières années, divers auteurs ont décrit divers appareils plus ou moins portatifs pour la concentration de virus (Wallis, Homma et Melnick, 1972; Payment et Trudel, 1980), mais nous avons jugé intéressant d'en dessiner un adapté aux propres necéssités de prélèvement et de concentration "in situ". Le schéma opératif du prototype est représenté par le Fig. 2.

Dans 10 expériences de recuperation de virus ajoutés (Polio 1 vaccinal LSc2ab), utilisant entre 0.01 et 1000 UFC/l., on a récuperé toujours des virus, avec un taux moyen de 26.5 %. Pour 2 expériences, la poudre de verre en série permet une récupération additionnelle entre 11.8 % et 35 %.

Le système mis au point a été essayé sur le terrain, donnant un résultat très opérationnel surtout pour l'étude des eaux souterraines et du réseau de distribution.

Détection des Entérovirus dans les Boues

Il n'existe pas, dans la bibliographie, une méthode développée pour la récupération (extraction) de virus à partir de boue obtenue par le processus de floculation/sédimentation pour rendre l'eau potable. Par contre, on peut trouver des réferences sur des méthodes d'extraction de virus à partir de sols contaminés et de sédiments marins et fluviaux (Hurst et Gerba, 1979; Bitton, Chou et Farrah, 1982; Gerba, 1982).

On a décidé d'adopter une méthode qui utilise le tampon glycine-EDTA a pH 11.5 comme liquide d'élution et -

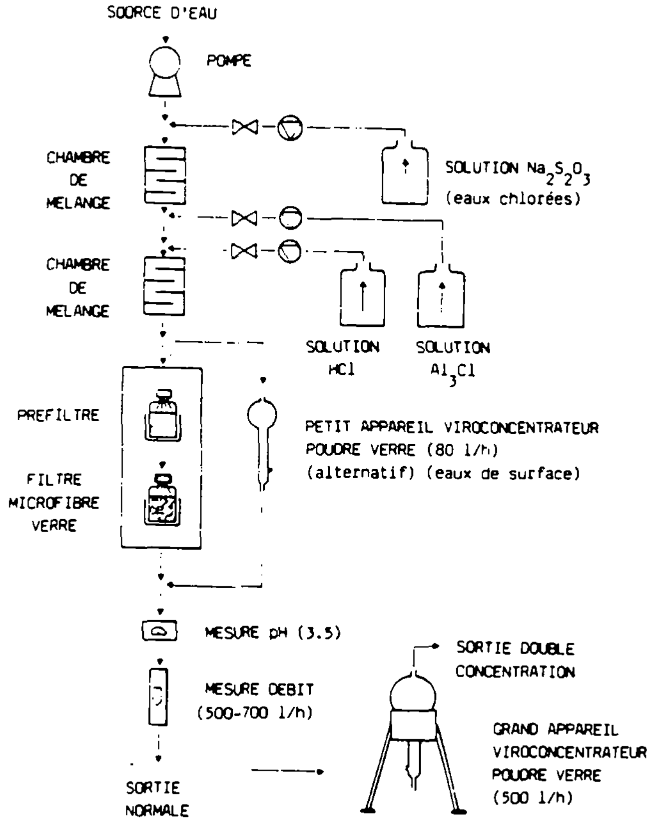

Fig. 2. Viroconcentreur polivalent sur le terrain

la floculation inorganique avec $AlCl_3$ comme système de concentration de ce liquide. Le protocole expérimental utilisé est indiqué sur la Fig 3.

Nous avons posé des expériences préalables avec addition des Polio 1 vaccinaux LSc2ab pour évaluer l'efficacité récupératrice et vérifier l'existence hypothétique des "fuites" de virus au niveau des nombreuses phases rejetées au cours de cette méthode complexe. La méthode permet des récupérations de plus du 70 % et dans aucune des phases rejetées le nombre de virus ne dépasse pas 1 par 10^3 ou 1 par 10^4 de ceux finalement recupérés.

La vérification de la méthode sur le terrain a été faite avec une série de prélèvements des boues d'une station pilote pour l'essai des méthodes d'épuration alternatifs. De cette façon, on faisait 14 déterminations de boues obtenues par un processus sans préchloration et 10 déterminations avec préchloration. Le pourcentage de positivité des prélèvements est bien superieur dans ceux qui correspondent aux moments sans chloration (50 %), par rapport au moment où celle-ci se faisait (10 %). Cependant, si on ne prend pas en consideration les prélèvements toxiques, les positivités deviennent 78 % et 50 %. Le problème principal, déjà attendu - d'après les données bibliographiques à propos des sols et des boues de tous genres, a été le nombre vraiment élevé d'échantillons qui sont toxiques quand ils sont inoculés dans la culture cellulaire.

ESSAIS DE SURVIE DES VIRUS AU TRAITEMENT AU NIVEAU D'UNE STATION PILOTE

Simulation dans le Laboratoire du Traitement Conventionel

Nous avons efectué diverses expériences préalables simulant, au niveau de laboratoire, le traitement réalisé au niveau des stations d'épuration, en ajoutant a l'eau de surface de la rivière Llobregat des virus Polio 1 vaccinal LSc2ab. Afin de clarifier l'efficacité relative du processus de préchloration au "break-point" et de floculation/décantation, simultanées dans la station d'épuration, on a essayé de floculer avant de chlorer et, vice-versa, de préchlorer avant de floculer. Nous retrovons seulement des virus dans l'eau de surface floculée et dans sa boue, ne se détectant pas sur 50 ml. d'une eau quelconque, floculée ou pas, prechlorée au break-point ni sur aucune boue d'eau préchlorée. Dans la boue non préchlorée, on observe une récupération importante ($5.3x10^5$ de 10^6) des virus théoriquement rajoutés. Dans l'eau, la floculation fait descendre 4 logarytmes le titre viral (jusqu'à une moyenne de $1.25,10^2$).

Nous avons effectué aussi des expériences pour déterminer quelle est la dose de chlore de sécurité à laquelle il faut postchlorer une eau préchlorée au "break-point", décantée et filtrée par charbon actif granulaire. Malgré que le chlore ajouté agit durant tout le temps qu'il reste dans l'eau, nous avons choisi un temps de chloration de 1 h., déterminant le chlore résiduel à la fin de ce temps. Tandis qu'avec une dose initiale de 0.50 ppm (0.20 dans 1 h.) on trouve une persistence d'un 10 % des virus ajoutés, une dose de 1 ppm (0.40 dans 1 h.) suffit pour les inactiver (dans l'usine de traitement on fait la postchloration de sûreté avec presque 2 ppm de chlore). De toutes façons, malgré la possibilité d'erreur dans le traitement, - qui oblige à un vrai contrôle de virus, il faut considérer la possibilité que les propres virus deviennent plus résistants à la chloration (Bates, Schaffer et Sutherland, 1977) (les essais sont effectués avec une

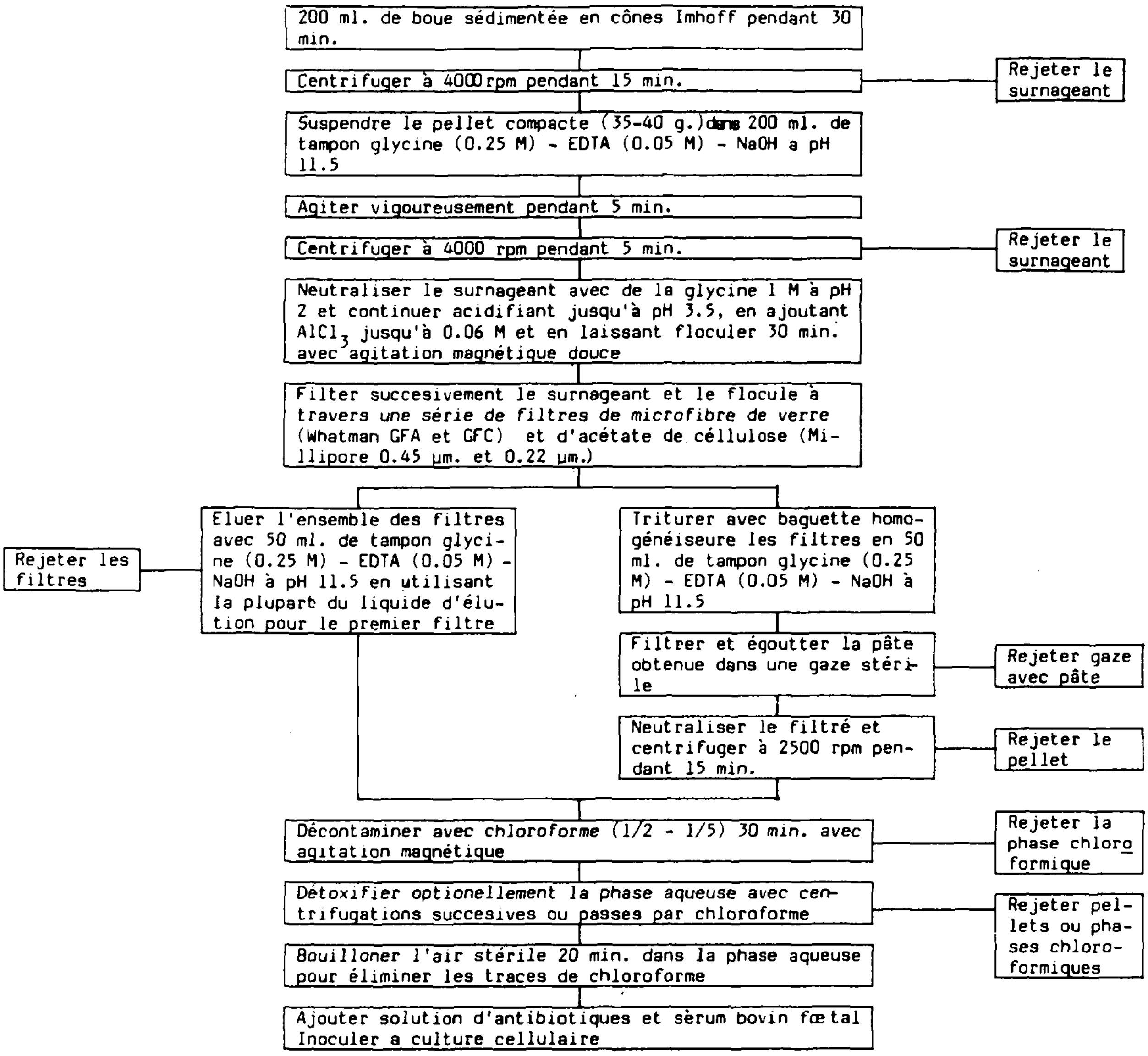

Fig. 3. Protocole expérimental pour l'extraction de virus de la boue

seule souche de virus vaccinal non aclimatée), ou bien ils se protègent par agrégation entre eux, ou par adsorption aux particules en suspension dans l'eau.

Survie des Virus dans une Station Pilote

Dans une station pilote, les expériences avec addition de virus à l'eau fluviale, pour étudier leur évolution à travers des diverses phases de traitement, ont commencé par un traitement biologique sans préchloration, destiné à reduire les niveaux d'ammoniaque, afin de limiter la géneration de dérivés halogénés.

D'autre part, pendant cet essai, nous avons commencé l'étude des Rotavirus. La mise au point de leur méthode était menée par le Département de Microbiologie (Bosch, Lucena et Jofre, 1986).

Parallèlement à l'évolution des virus, nous suivions les différents paramètres bactériens. Cependant, les différents niveaux de concentration auxquels se présentent les bactéries et les virus d'origine fécal dans l'eau fluviale conseillent une stratégie différente si nous désirons étudier leur évolution au niveau du traitement des eaux. L'analyse bactériologique est effectuée sur les organismes réellement présents dans l'eau; par contre, les Entérovirus et Rotavirus, pour garantir leur présence, sont ajoutés à l'eau brute au niveau du captage. Nous avons utilisé le virus Polio 1 vaccinal LSc2ab et Rotavirus de singe SA 11 (ATCC VR 899).

Les points de prélèvement correspondent à la séquence du traitement effectué: entrée (E) eau brute (8 l./sec.); eau décantée (D), après la floculation avec sulfate d'aluminium et polyélectrolyte cationique LT24 - et sédimentation; eau filtrée (F), par charbon actif granulaire Chemviron TL8017; eau chlorée (Cl) avec hypochlorite sodique. La concentration des virus à partir de l'eau a été faite avec des cartouches filtrantes électronégatives de microfibre de verre (Whatman 80-12).

Les données bactériologiques et virologiques obtenues (Tableau 3) suggèrent quelques considérations. Dans les conditions de l'expérimentation, nous n'avons pas détecté d'Entérovirus ni de Rotavirus, en moyenne sur

TABLEAU 3 Evolution de Virus et Bactéries dans une Station Pilote, sans Préchloration

	Enterovirus UFC/l.	Rotavirus FF/l.	Aérobies totaux 37 ºC. UFC/ml.	Colif. totaux NMP/100 ml.	Colif. fecaux NMP/100 ml.	Entéro coques NMP/100 ml.	Clostridium spores/ 100 ml.
E	155 ± 103	55.5 ± 25.2	402750 ± 125469	1.2×10^6 ± 7.4×10^5	1.8×10^5 ± 1.6×10^5	8.7×10^3 ± 8.9×10^3	3200 ± 2605
D	46.5 ± 23.4	14.3 ± 8.4	142725 ± 165879	2.4×10^5 ± 0	5.5×10^4 ± 3.9×10^4	1.0×10^3 ± 8.1×10^2	737 ± 516
F	11.8 ± 7.4	3.5 ± 3.2	59600 ±72667	1.3×10^5 ± 1.1×10^5	1.8×10^4 ± 1.6×10^4	3.9×10^2 ± 9.2×10^1	214 ± 184
Cl	0 ± 0	0 ± 0	19 ± 25	0.5 ± 0.87	0 ± 0	3.2. ± 3.7	49 ± 82

E, eau brute / D, eau decantée / F, eau filtrée / Cl, eau chlorée

123 l. d'eau chlorée. On n'observe pas de différences significatives de comportement entre les Entérovirus et les Rotavirus au niveau du traitement, avec une efficacité presque identique de la filtration et de la décantation pour la réduction de leurs niveaux respectifs. Sur les paramètres bactériens, on observe une disparation totale des coliformes fécaux et des pourcentages supérieurs au 99 % de coliformes totaux, aérobies et entérocoques, tandis que les spores de Clostridium disparaissent seulement dans un 90 %. Il existe une réduction de tous les paramètres bactériens entre la décantation et la filtration.

De façon comparable aux expériences de laboratoire, le premier essai effectué avec préchloration, au niveau de la station pilote, avec addition des mêmes niveaux de virus à l'entrée, pose le problème de son élimination totale dans le processus de préchloration. Les expériences actuellement en projet prévoient l'addition de doses plus élevées de virus au niveau de chacune des phases du traitement.

CONTRÔLE DU BASSIN DU LLOBREGAT

Dans une publication antérieure (Ribas, Huguet et Perramón, 1986) nous décrivions 10 points de prélèvement (6 du cours principal et 4 des affluents de divers stades de contamination), pour l'étude de la pollution virale dans le bassin du Llobregat et nous indiquions les résultats des deux premières années de l'étude.

On dispose en ce moment des données de 6 années (1981-1986) à raison de 7 prélèvements des 10 points par an. En plus des Entérovirus, nous avons déterminé 13 autres paramètres: 8 physico-chimiques et 5 de caractère bactérien. L'ensemble des données a été soumis à un programme statistique (BMP4M-Factor Analysis. Univ. of California) qui comprend une matrice de corrélations, corrélations multiples et parciales et analyse de la variance multifactoriel (composantes principaux).

Au Tableau 4 sont indiqués les moyennes et les déviations standard du débit et des paramètres microbiologiques pour les 10 points de prélèvement. Au Tableau 5 on peut voir l'évolution des niveaux d'Entérovirus aux divers points, en fonction des années succesives.

Le Tableau 6 montre toutes les corrélations significatives entre les divers paramètres avec un niveau de confiance du 95 % (risque $\alpha = 0.05$), en ce qui concerne les divers points, pour l'ensemble du Llobregat, de ses affluents et du bassin. Au Tableau 7 on exprime pour chaque point les corrélations carrées multiples (SMC) de chaque variable avec toutes les autres variables.

Premièrement, toutes les paires possibles de corrélations (91) se présentent au minimum une fois dans un point de prélèvement ou dans une considération globale. Deux paires uniquement se répètent dans tous les points et considérations globaux: la positive Coliformes totaux - Coliformes fécaux (expliquée en raison de leur relation intime) et la négative Débit - Conductivité, comme l'expression la plus élevée du facteur dilution. Dans cette ligne, on peut expliquer aussi les importantes corrélations négatives Débit - Chlorures et Débit - Ammoniaque. Conductivité - Chlorures présente des valeurs très elevées, positives dans tous les points, avec l'exception du point 1 (cela peut s'expliquer par sa basse teneur en chlorures). Entre les points 1 et 2 il y a l'importante pollution des mines de potasse, qui fait augmenter la valeur des chlorures qui deviennent la composante principale de la conductivité (observez les SMC très pareilles).

Sans arriver aux hauts niveaux de Coliformes totaux - Coliformes fécaux, les autres corrélations entre paramètres bactériens sont toujours positives, étant significatives à touts les niveaux globaux (avec l'exception Clostridium - Entérocoques). L'Ammoniaque est correlationné positivement avec les bactéries (dans toutes les considérations globaux et au minimum dans le 40 % des points de prélèvement.

On observe que parmi les correlations où interviennent les Entérovirus, la pluplart se présentent dans les niveaux globaux (où l'exigence pour un niveau de confiance d'un 95 % est inférieure, parce que le nombre de données est beaucoup plus élevé), et quelques-unes dans les points concrets 10 (pH - Entéterovirus) et 5 (les autres).Si on observe les SMC, les Enterovirus sont placés presque toujours en dernier lieu en ordre décroissant de valeur, excepté dans les points 8 et 5 (où se trovent la plupart des correlations significatives).

De tout cela, on peut en déduire la corrélation très basse que les Entérovirus présentent en général en comparaison avec les autres paramètres: un nouveau argument à faveur de la nécessité de leur contrôle.

Dans le Tableau 8, on indique les principales variables qui influent dans chacun des facteurs obtenus dans l'analyse factoriel. Pour chaque paramètre (variable) on indique tous les facteurs dont leur poids est superieur à 0.250 en valeur absolue, arrangés dès le poids plus haut au poids plus bas, considérant dans chaque

TABLEAU 4 Données Microbiologiques du Bassin Llobregat

	1 Haut Llobregat I (Balsareny)	2 Haut Llobregat II (Pont de Vilomara)	4 Moyen Llobregat (Martorell)	6 Bas Llobregat I (Papiol)
Débit	7.33 ± 4.32	8.88 ± 6.31	12.63 ± 9.57	15.01 ± 12.36
Coliformes totaux	$7.8 \times 10^4 \pm 1.1 \times 10^5$	$1.0 \times 10^5 \pm 2.0 \times 10^5$	$1.1 \times 10^5 \pm 1.3 \times 10^5$	$2.1 \times 10^6 \pm 4.9 \times 10^6$
Coliformes fécaux	$2.3 \times 10^4 \pm 4.4 \times 10^5$	$3.0 \times 10^4 \pm 8.0 \times 10^4$	$1.6 \times 10^4 \pm 1.7 \times 10^4$	$3.9 \times 10^5 \pm 1.8 \times 10^6$
Aérobies totaux	13829 ± 23248	42163 ± 111967	106134 ± 285172	615846 ± 1004081
Clostridium	614 ± 4.1	849 ± 518	1055 ± 785	955 ± 760
Entérocoques	$2.1 \times 10^3 \pm 2.5 \times 10^3$	$4.0 \times 10^3 \pm 7.1 \times 10^3$	$2.8 \times 10^3 \pm 5.0 \times 10^3$	$1.5 \times 10^4 \pm 49.7$
Entérovirus	11.3 ± 59.0	8.2 ± 31.6	13.3 ± 59.0	14.0 ± 49.7
	29.4	36.1	28.6	35.7

	7 Bas Llobregat II (S. Joan Despí)	8 Bas Llobregat III (Mercabarna)
Débit	16.03 ± 13.31	16.03 ± 13.31
Coliformes totaux	$1.3 \times 10^6 \pm 3.6 \times 10^6$	$8.9 \times 10^6 \pm 1.1 \times 10^7$
Coliformes fécaux	$3.0 \times 10^5 \pm 1.2 \times 10^6$	$2.0 \times 10^6 \pm 2.7 \times 10^6$
Aérobies totaux	220722 ± 215181	2114250 ± 1942924
Clostridium	1360 ± 1007	3800 ± 3299
Entérocoques	$3.1 \times 10^4 \pm 1.6 \times 10^5$	$7.7 \times 10^4 \pm 9.6 \times 10^4$
Entérovirus	4.9 ± 13.9	19.4 ± 29.3
	28.6	61.1

Débit, m^3/sec.
Coliformes totaux, NMP/100 ml.
Coliformes fécaux, NMP/100 ml.
Aérobies totaux 37º, UFC/ml.
Clostridium, spores/100 ml.
Entérocoques, NMP/100 ml.
Entérovirus, UFC/50 l.
% +

	3 Cardener (fin)	5 Anoia (fin)	9 Rubí (fin)	10 Collecteur St. Feliu (fin)
Débit	2.27 ± 1.73	1.02 ± 0.93	1.16 ± 0.81	0.79 ± 0.25
Coliformes totaux	$2.2 \times 10^5 \pm 2.1 \times 10^5$	$1.9 \times 10^7 \pm 4.4 \times 10^7$	$2.1 \times 10^7 \pm 4.0 \times 10^7$	$4.3 \times 10^7 \pm 5.1 \times 10^7$
Coliformes fécaux	$8.0 \times 10^4 \pm 9.3 \times 10^4$	$8.7 \times 10^5 \pm 1.4 \times 10^6$	$8.0 \times 10^6 \pm 1.8 \times 10^7$	$1.1 \times 10^7 \pm 1.3 \times 10^7$
Aérobies totaux	151700 ± 185716	4980143 ± 7708208	14476210 ± 30150359	13954762 ± 25138769
Clostridium	2093 ± 1471	4956 ± 4903	32967 ± 43625	34822 ± 32755
Entérocoques	$6.8 \times 10^3 \pm 5.9 \times 10^3$	$1.0 \times 10^5 \pm 2.2 \times 10^5$	$3.8 \times 10^5 \pm 6.0 \times 10^5$	$7.3 \times 10^5 \pm 8.2 \times 10^5$
Entérovirus	7.9 ± 17.2	14.4 ± 65.6	73.7 ± 200.2	120.1 ± 264.7
	42.6	50.0	85.3	79.4

TABLEAU 5 Entérovirus du Bassin de la Rivière Llobregat

		1981	1982	1983	1984	1985	1986
$\bar{x} \pm s$	1. A. Ll. I	9.8 ± 21.4	2.6 ± 4.1	0 ± 0	49 ± 119	1.1 ± 1.8	1.3 ± 1.1
	2. A. Ll. II	3.5 ± 3.9	0 ± 0	0 ± 0	31 ± 62	4.7 ± 6.6	3.5 ± 4.8
	4. Ll. Medio	11.7 ± 25.9	1.6 ± 1.8	1.1 ± 1.8	49 ± 111	1.7 ± 3.5	13.3 ± 32.5
	6. B. Ll. I	27.4 ± 54.4	3.1 ± 5.4	0 ± 0	62 ± 95	3.1 ± 5.0	1.4 ± 2.6
	7. B. Ll. II	2.9 ± 4.6	6.1 ± 15	0 ± 0	13 ± 24	5.0 ± 4.5	0.3 ± 0.7
	8. B. Ll. III	7.9 ± 13.1	9.8 ± 15	11 ± 24	37 ± 36	27.4 ± 35.5	9.3 ± 7.1
	3. Cardener	24 ± 31.7	6.4 ± 8.6	0 ± 0	25 ± 29	5.1 ± 7.4	1.8 ± 2.0
	5. Anoia	12.2 ± 20.6	3.4 ± 3.4	0 ± 0	3.5 ± 2.7	7.0 ± 1.5	61.3 ± 134.5
	9. Riera Rubí	4184 ± 8152	249 ± 345	7.8 ± 7.9	112 ± 116	23.9 ± 25.6	6.6 ± 7.8
	10. C. St. Feliu	482 ± 1100	264 ± 338	43 + 39	193 ± 375	63.2 ± 63.7	32.2 ± 43.9
% +	1. A. Ll. I	42.9	28.6	0.0	14.3	33.3	57.1
	2. A. Ll. II	57.1	0.0	0.0	42.9	50.0	66.7
	4. Ll. Medio	42.9	42.9	28.6	14.3	28.6	14.3
	6. B. Ll. I	57.1	28.6	0.0	71.4	28.6	28.6
	7. B. Ll. II	28.6	14.3	0.0	42.9	71.4	14.3
	8. B. Ll. III	57.1	50.0	16.7	85.7	85.7	71.4
	3. Cardener	57.1	43.9	0.0	71.4	33.3	50.0
	5. Anoia	71.4	57.1	0.0	71.4	57.1	42.9
	9. Riera Rubí	100.0	100.0	71.4	85.7	71.4	83.3
	10. C. St. Feliu	100.0	85.7	71.4	85.7	83.3	50.0

point de prélèvement seulement les facteurs nécessaires pour expliquer jusqu'à 80 % de la variance. La ligne sur un numéro indique que le poids du paramètre dans le facteur est en corrélation négative avec les autres. A chaque point on indique le paramètre avec le poids le plus élevé dans le premier facteur avec le signe (1).

On observe que les chlorures, liés dans leurs poids principaux avec la conductivité, constituent la composante principale du premier facteur dans 5 des 10 points de prélèvement. Si on y ajoute le conditionnel "chlorures on conductivité", l'affirmation anterieure est vraie pour 6 des 10 points. 4 de ces 6 sont précisément les points du Llobregat postérieurs à la pollution saline. Le point 7 est l'exception à cette règle: le poids principal dans le facteur 1 correspond aux paramètres bactériens (surtout Entérocoques, Coliformes totaux et Coliformes fécaux). Les deux affluents où le poids de la conductivité et les chlorures est le plus

TABLEAU 6 Corrélations Significatives entre les Paramètres

	Global			Llobregat						Affluents			
	L	A	B	1	2	4	6	7	8	3	5	9	10
C.T. - C.F.	+	+	+	+	+	+	+	+	+	+	+	+	+
CON - CHL	+	+	+		+	+	+	+	+	+	+	+	+
CON - AMM	+	+	+	+	+	+	+	+	+	+	+	+	
C.F. - A.T.	+	+	+				+	+	+	+	+	+	+
C.T. - E.F.	+	+	+		+	+	+	+			+	+	+
AMM - C.S.	+	+	+		+	+	+	+	+	+		-	
TAC - AMM	+	+	+		-	+		+	+		+	-	+
TEM - TAC	+	+	+	-	-	-	-		+	-	+		
TAC - C.S.	+	+	+			+	+	+	+		+		+
AMM - A.T.	+	+	+	+	+			+	+	+	+		
C.T. - A.T.	+	+	+				+	+		+	+	+	+
C.F. - E.F.	+	+	+	+		+	+	+			+	+	
TEM - C.F.	+	+	+				+		+		+	+	+
TUR - C.S.	+	+	+			+	+	+	+		+		
AMM - C.F.	+	+	+			+		+	+		+		+
A.T. - E.F.	+	+	+		+		+	+			+		+
TEM - C.T.	+	+	+			-	+		+	+		+	
TEM - A.T.	+	+	+						+	+		+	+
TUR - C.T.	+	+	+				+	+	+			+	
TAC - C.T.	+	+	+					+	+		+		+
TAC - C.F.	+	+	+					+	+		+		+
TAC - E.F.	+	+	+						+	+	+		+
AMM - C.T.	+	+	+		+	+		+	+				
AMM - E.F.	+	+	+	+	+			+			+		
C.T. - C.S.	+	+	+			+	+	+				+	
C.F. - C.S.	+	+	+			+		+		+			+
TAC - A.T.	+	+	+	-					+		+		+
TEM - C.S.	+	+	+	-	-	-			+				
TUR - TAC	+	+	+				+		+				+
TUR - A.T.	+	+	+				+	+				+	
TUR - E.F.	+	+	+				+	+			+		
TUR - C.F.	+	+	+					+				+	
A.T. - C.S.	+	+	+		+		+						
CHL - AMM	+		+	+	+	+	+	+	+	+	+	+	
DEB - pH	+		+		+	+	+	+	+	+	-	-	
CON - A.T.	+		+		+		+		+	+	+		+
CHL - A.T.	+		+	+	+		+		+	+	+		
DEB - TUR	+	+			+	+		+			+	+	
CHL - C.F.	+		+				+		+	+	+		+
CON - C.T.	+		+						+	+	+		+
CON - C.F.	+		+						+	+	+		+
C.S. - E.F.	+	+				+	+	+					+
CHL - E.F.	+		+	+			+				+		+
CHL - C.T.	+		+						+	+	+		
TUR - AMM	+		+		-			+	+				
CON - C.S.	+		+						+	+		-	
TEM - CHL	+		+						+		+		
CON - E.F.	+		+								+		+
TEM - TUR	+		+						+				-
CHL - C.S.	+		+						+			-	

	Global			Llobregat						Affluents			
	L	A	B	1	2	4	6	7	8	3	5	9	10
TEM - CON	+		+						+				
TEM - ENT		+	+								+		
TAC - ENT		+	+								+		
C.F. - ENT		+	+								+		
A.T. - ENT		+	+								+		
TUR - ENT		+	+										
C.T. - ENT		+	+										
C.S. - ENT		+	+										
TEM - AMM	+				-	-	-	-	+		+	-	
TUR - CON	+			-	-	-				-			-
TUR - CHL	+				-	-			+	-			
DEB - CON	-	-	-	-	-	-	-	-	-	-	-	-	-
DEB - CHL	-	-	-	-	-	-	-	-	-	-	-	-	
DEB - AMM	-	-	-		-		-	-	-	-	-		
DEB - TEM	-	-	-			-	-	-	-		-		
TEM - pH	-	-	-			+			-	-		-	-
pH - CHL	-		-	-	-	-	-	-	-	-			
pH - CON	-		-		-	-	-	-	-	-			
pH - C.T.	-		-	+		-	-		-	-			
pH - TAC	-		-	+	+		+		-	+			
pH - C.F.	-		-	+		-			-				-
DEB - E.F.		-	-		+	+	-			+			
pH - C.S.	-		-		-				-	-			
pH - E.F.	-		-				-						
pH - A.T.	-			-	-	-	-	-	-	-			
DEB - A.T.			-				-		-	-	-	+	
DEB - C.F.			-						-		-	+	
DEB - C.S.			-							-		+	
DEB - C.T.			-						-			+	
TUR - pH	-												-
DEB - ENT			-										
TAC - CON	+	-	+	-	-	-		+	+		+		+
TAC - CHL	+	-	+	-	-	-			+		+		+
DEB - TAC	+	-	-	+	+	+	+		-		-		-
pH - AMM	-	+			-	-	-	-	-	-			+
CON - ENT											+		
CHL - ENT											+		
AMM - ENT											+		
E.F. - ENT											+		
TEM - E.F.				-	-	-				-			
pH - ENT													-

L - Llobregat DEB, débit TAC, alcalinité C.T., coliformes totaux E.F., enterocoques
A - Affluents TEM, température CON, conductivité C.F., coliformes fecaux ENT, entérovirus
B - Bassin TUR, turbidité CHL, chlorures A.T., aérobies
pH, pH AMM, ammoniaque C.S., clostridium

TABLEAU 7 SCM de Chaque Variable avec Toutes les Autres Variables

	1	2	4	6	7	8	3	5	9	10	Llob.	Afl.	Bassin
Débit	0.419	0.681	0.771	0.762	0.804	0.825	0.752	0.681	0.914	0.500	0.392	0.504	0.223
Température	0.583	0.660	0.759	0.572	0.744	0.657	0.704	0.390	0.554	0.521	0.256	0.199	0.084
Turbidité	0.407	0.620	0.707	0.854	0.938	0.784	0.392	0.678	0.974	0.477	0.581	0.649	0.607
pH	0.512	0.715	0.679	0.514	0.598	0.678	0.780	0.146	0.432	0.697	0.505	0.066	0.126
TAC	0.610	0.692	0.617	0.510	0.620	0.862	0.585	0.846	0.622	0.725	0.798	0.578	0.643
Conductivité	0.486	0.776	0.989	0.983	0.967	0.992	0.982	0.968	0.909	0.731	0.981	0.886	0.941
Chlorures	0.500	0.827	0.989	0.983	0.969	0.990	0.976	0.976	0.941	0.447	0.980	0.889	0.933
Ammoniaque	0.442	0.865	0.708	0.756	0.899	0.929	0.784	0.739	0.770	0.447	0.825	0.310	0.515
Coliformes totaux	0.662	0.905	0.745	0.946	0.991	0.720	0.711	0.825	0.924	0.716	0.710	0.735	0.746
Coliformes fécaux	0.776	0.887	0.691	0.886	0.986	0.808	0.674	0.864	0.894	0.786	0.713	0.758	0.764
Aérobies	0.342	0.701	0.550	0.789	0.539	0.671	0.785	0.879	0.948	0.716	0.554	0.771	0.767
Clostridium	0.298	0.507	0.524	0.712	0.496	0.721	0.468	0.496	0.356	0.649	0.644	0.292	0.385
Entérocoques	0.503	0.745	0.490	0.676	0.990	0.327	0.537	0.815	0.378	0.685	0.407	0.531	0.568
Entérovirus	0.128	0.141	0.068	0.234	0.287	0.515	0.238	0.740	0.181	0.248	0.027	0.087	0.105

TABLEAU 8 Principaux Variables pour Chaque Facteur de la Variance

	1	2	4	6	7	8	3	5	9	10	Llob.	Afl.	Bassin
Débit	$\bar{1}$,$\bar{6}$,4 $\bar{7}$	$\bar{1}$,2,$\bar{6}$ 5,$\bar{4}$	$\bar{1}$,$\bar{6}$	$\bar{1}$,2	$\bar{2}$	$\bar{1}$,4,2	$\bar{1}$,2,3	2,$\bar{1}$	1,$\bar{5}$,$\bar{4}$	3,$\bar{5}$,2 6,1	2,6	3,$\bar{2}$	7,$\bar{2}$,$\bar{1}$
Température	3,$\bar{2}$	$\bar{2}$,4,5	$\bar{2}$,$\bar{3}$,1	$\bar{3}$,5,1	3,4	1,$\bar{3}$	3,$\bar{2}$,1	5,4,1 3,$\bar{2}$	1	5,2	5,4,1 $\bar{2}$,3	$\bar{4}$,7,$\bar{6}$ 1	4,6,$\bar{3}$
Turbidité	4,$\bar{6}$,$\bar{1}$ 7	4,$\bar{1}$,2 6,5	$\bar{1}$,6,4 $\bar{3}$	2,1,5 $\bar{4}$	1,$\bar{2}$	2,1	4,$\bar{6}$,$\bar{5}$	2,3	$\bar{3}$,1,4 6	3,$\bar{2}$,6	2,1,5 $\bar{6}$	1,3	1,$\bar{2}$,5 $\bar{3}$,7
pH	2,3,$\bar{1}$	$\bar{1}$	$\bar{2}$,$\bar{4}$,$\bar{1}$	$\bar{1}$,2	4,$\bar{2}$,$\bar{1}$ $\bar{3}$	$\bar{1}$	$\bar{1}$,$\bar{4}$,2	$\bar{4}$,3	3,5	$\bar{3}$,$\bar{2}$,$\bar{5}$	$\bar{1}$	4,7,5	5,6,$\bar{4}$ 3,$\bar{2}$
TAC	($\bar{1}$),6,2	$\bar{1}$,2	3,$\bar{1}$,4 $\bar{5}$	4,3,2	$\bar{3}$,1,4 5	1,2	2,$\bar{4}$	1	4,$\bar{2}$	1,$\bar{2}$,4	1,$\bar{3}$	$\bar{3}$,1	1,3
Conductivité	1,$\bar{5}$,6	1,$\bar{2}$	1	1,$\bar{2}$	2,1	1	(1),$\bar{3}$	1	2,$\bar{1}$	1,3,$\bar{2}$	1,$\bar{2}$,$\bar{3}$	2	2,1,3
Chlorures	1,$\bar{3}$	(1),$\bar{2}$	(1)	(1),$\bar{2}$	2,1	(1)	1,$\bar{3}$	(1)	2,$\bar{1}$	1,$\bar{6}$,3 $\bar{4}$,5,$\bar{2}$	1,$\bar{2}$,$\bar{3}$	2,3	2,1,$\bar{3}$
Ammoniaque	1,7,4	1,2	2,3	3,1	1,$\bar{3}$,2	1,3	1,$\bar{3}$	1,$\bar{2}$	2,$\bar{1}$,$\bar{4}$ 3	6,4,$\bar{2}$ 1,3	(1)	$\bar{3}$,1,4 2	1,3,2
Colif. totaux	2,3,1	3,2,1	2,$\bar{3}$	1,2,$\bar{3}$	1,$\bar{2}$	1,4,$\bar{5}$	1,3,2 $\bar{5}$	1,$\bar{3}$,$\bar{4}$ 2,5	(1)	1,3,2	1,3	1	1,$\bar{2}$
Colif. fécaux	2,3,1	3,2,1	2,$\bar{3}$	1,$\bar{3}$,4	1	1,$\bar{2}$,4 $\bar{3}$	2,1,3 6	1,$\bar{3}$,5	1,2	(1),2	1,3	(1),3	(1),$\bar{2}$
Aérobies	1,6,4 5	1,$\bar{3}$,5 2	4,1,$\bar{6}$	1,2	1,3	1,5,$\bar{4}$ $\bar{2}$	1,3,2	1	1	1,7,2 $\bar{4}$	1	1,3,$\bar{6}$	1,$\bar{2}$
Clostridium	$\bar{3}$,$\bar{4}$,2	2,1,$\bar{3}$	2,$\bar{1}$,6	2,3,1	1,4,$\bar{3}$	2,1	6,$\bar{5}$,4 1,2	3,2	1,$\bar{4}$,$\bar{3}$ $\bar{2}$	4,$\bar{5}$,1 2,$\bar{7}$	1,$\bar{3}$,2 6	6,1,7	1,3,7
Entérocoques	1,2,$\bar{7}$ $\bar{3}$	2,5,1	2,$\bar{6}$,$\bar{3}$ $\bar{1}$	1,2	(1)	3,$\bar{2}$,$\bar{5}$	6,4,5	1,2,$\bar{3}$	5,2,1	1,$\bar{5}$	1,3,2 $\bar{6}$	1,6,$\bar{5}$	1,7,$\bar{5}$
Entérovirus	5,6	$\bar{4}$,5,$\bar{6}$ 2	5	5,4	5,3	$\bar{4}$,$\bar{3}$,2 $\bar{5}$	5,3	4,1	6,3,5 1	4,7,2 $\bar{6}$,5	4,$\bar{5}$,$\bar{3}$	5,1	4,5,$\bar{6}$ 1,3

élevé sont aussi les moins pollués. Dans les affluents les plus pollués, le poids le plus élevé dans la variance correspond aux Coliformes totaux (point 9) ou Coliformes fécaux (point 10). Le poids des paramètres microbiens est plus élevé dans les points plus contaminés et dans les considérations globaux (dans les affluents et le bassin la composante principale du facteur 1 est Coliformes fécaux).

Il est très intéressant de souligner que le Débit apparaît dans les points du Llobregat avec son poids plus élevé en corrélation négative avec d'autres variables (surtout conductivité et chlorures) dans le facteur 1 ou 2 (point 7). Ce comportement seulement existe dans l'affluent le moins pollué (3, Cardener). Dans les autres, la perte de poids peut être expliquée en considérant qu'il s'agit des débits très bas et relativement constants, plutôt que d'un problème de pollution microbienne. Dans les considérations globaux, il est évident que le Débit perd du poids, considérant dans le même ensemble des points avec des débits becaucoup plus différents entre eux que la majorité des autres variables, tandis que les paramètres microbiens sont beaucoup moins hétérogènes.

Dans l'ensemble du fleuve Llobregat, le paramètre avec un poids plus élevé dans le facteur 1 est l'Ammoniaque, qui présente, comme on a déjà vu, de bonnes corrélations avec les paramètres bactériens. On observe que, entre les correlations où interviennent les Entérovirus, la plupart se présentent dans les niveaux globaux (où l'exigence pour un niveau de confiance d'un 95 % est inferieure, parce que le numéro de données est beaucoup plus élevé), et quelques unes dans les points concrets 10 (pH - Entérovirus) et 5 (les autres).

Les Entérovirus ont un poids très limité dans l'explication de la variance. Le poids principal est dans le facteur 4 (6 fois), 5 (6 fois) ou 6 (une fois). Néanmoins, dans quelques points (5 et 9), l'ensemble des affluents et du bassin ont un poids supérieur à 0.250 dans le facteur 1. Le poids le plus élevé se trouve dans le point 5, comme prévu d'accord avec l'étude de corrélations, étant la composante principale du facteur 4 (où sa correlation est négative avec Coliformes totaux et pH et positive avec Temperature) et ayant un poids relativement important (0.583) dans le facteur 1.

CONTRÔLE DU PROCESSUS D'EPURATION DANS LA STATION DE TRAITEMENT

Dans un travail antérieur (Ribas et Oromí, 1985) on recueillit l'évolution des différents paramètres physico-chimiques et biologiques au niveau du traitement: préchloration au "break-point", floculation avec sulfate d'aluminium et polyélectrolyte; filtration par charbon actif granulaire (GAC); postchloration de sécurité. Ceci nous donne 4 points de prélèvement dans la station de traitement: eau brute (point 7 du contrôle du bassin du Llobregat), eau décantée, eau filtré eau épurée.

En ci qui concerne les paramètres microbiologiques, l'évolution en pourcentage de l'élimination de ceux-ci (avec de nouvelles données) est contenue sur le Tableau 9. Les spores de Clostridium est le seul paramètre bactérien qui n'augmente pas de l'eau décantée à l'eau filtrée. Cette particularité est aussi certaine pour les expériences de station pilote menées à terme avec préchloration. Cépendant, quand on n'a pas utilisé préchloration, le nombre de bactéries à la sortie des filtres a été toujours inférieur à celui de l'eau décantée.

TABLEAU 9 Pourcentage d'Elimination des Divers Paramètres Microciens

	Decantée		Filtrée		Epurée	
	% inic.	% ant.	% inic.	% ant.	% inic.	% ant.
Coliformes	-99.996	-99.996	-99.995	+46.2	-99.999995	-99.91
Aérobies	-99.98	-99.98	-99.95	+271.7	-99.9987	-97.7
Clostridium	-99.1	-99.1	-99.3	-20.0	-99.9977	-99.7
Entérovirus			-99.98	+99.98	-99.9999	-99.6

TABLEAU 10 Charactéristiques Microbiologiques des Eaux Souterraines

		Llobregat								Besós	
		Cornellá						St. Feliu			
		1	2	3	4	5	6	7	8	9	10
Aérobies 37 ºC.	UFC/100 ml.	4918	22600	2200	22000	9600	5920	30800	5000	14700	12500
Coliformes totaux	UFC/100 ml.	0	0	9	0	23	43	0	3	0	0
Coliformes fecaux	UFC/100 ml.	0	0	0	0	0	0	0	0	0	0
Entérocoques	UFC/100 ml.	0	0	0	0	0	0	0	0	0	0
Spores *C. perfringens*	UFC/100 ml.	0	0	0	0	1	0	2	0	0	0
Champ. et lévures	UFC/100 ml.	0	700	0	0	0	100	0	0	0	0
Phages *E. coli*	dans 100 ml.	-	-	-	-	+	-	-	-	-	-
Entérovirus	dans 1000 l.	-	-	-	-	-	-	+	+	-	-

Il est intéressant de constater l'existence d'un isolement positif d'Entérovirus dans l'eau filtrée et d'un autre dans l'eau épurée (avec, bien sur, peu de temps de contact dès presque 2 ppm du chlore libre de post-chloration), mais on n'a pu jamais détecter des virus dans le réseau de distribution. La présence de virus dans les dernières phases du traitement pourrait s'expliquer par le fait que, bien que non détectés ou indétectables dans l'eau décantée à cause d'une possible présence faible, ils seraient concentrés et retenus dans les filtres, où, avec l'absence presque totale de chlore et protégés dans leur adsorption aux particules de charbon, ils pourraient résister plus longtemps. Sous des conditions déterminées de comblement ou de fonctionnement des filtres, des substances organiques adsorbées au GAC pourraient commencer à se libérer, parmi d'autres des Entérovirus dans de concentrations déjà détectables, qui dans cette phase de leur cycle agissent comme de simples macromolécules. D'autre part, les Entérovirus peuvent être protégés par fixation aux particules en suspension libérées des filtres de façon comparable au phénomène décrit pour les bactéries (Lechevalier et d'autres, 1984). La dynamique microbiennse de la filtration par charbon actif, même l'adsorption de virus, est un des objectifs fondamentaux de la nouvelle phase de recherche de virus.

CONTRÔLE DES EAUX SOUTERRAINES

Un nombre chaque fois plus élevé d'epidémies de gastroentérite et d'hépatite A a mis en évidence leur origine dans les eaux souterraines. Cela nous oblige à connaitre la dynamique de la transmission des microorganismes responsables ou des indicateurs adéquats à travers des aquifères et nous pose la nécessité d'établir des critères de désinfection et de potabilité des eaux faisant appel aux virus animaux.

Suivant cette ligne de recherche, nous avons effectué une première prospection des aquifères des deltes des rivières Besos et Llobregat, qui contribuent en petite proportion (4-7 %) à l'approvisionnement d'eau potable pour la zone métropolitaine de Barcelone. Nous avons fait des prélèvements avec le viroconcentreur portatif dans 10 puits différents, 8 d'entre eux appartenant à l'aquifère profond du delta du Llobregat et 2 à l'aquifère du Besos. Antérieurement au prélèvement, on a arrêté la chloration "in situ" des puits. 33 paramètres ont été analysés, 25 du genre physico-chimique et 8 du genre microbiologique. Pour la recherche des virus animaux, nous avons analysé 1000 l. d'eau, en utilisant des cartouches filtrantes électronégatives de microfibre de verre, installées dans le viroconcentreur portatif. De l'ensemble des résultats obtenus, ceux correspondant aux paramètres microbiologiques sont indiqués dans le Tableau 10.

Il est intéressant de constater le pourcentage élevé de prélèvements positifs pour les virus (20 %), en comparaison avec les données de la bibliographie (Keswick et Gerba, 1980; Vaughn et Landry, 1983). Les deux prélèvements positifs correspondent aux puits de l'aquifère du Llobregat situés relativement près de la rivière et, surtout, d'un collecteur d'eau résiduaire. De toute façon, aucun des puits à contamination virale ne présente des coliformes fécaux ni des entérocoques. Du point de vue microbiologique, tous les prélèvements doivent être considérés légalement comme potables. Ces données démontrent l'inviabilité des critères de potabilité bacteriologique pour évaluer le risque de contamination virale, un argument additionel en faveur de la nécessité du contrôle de virus.

PERSPECTIVES

Comme nous l'avons déjà indiqué, la décade des années soixante posa pour la première fois le problème de la transmission des virus entériques, dans son double aspect épidémiologique et méthodologique. La décade des années soixante-dix servit pour consolider, dans la mesure du possible, les lignes de travail plus adéquates en ce qui concerne la concentration, arrivant jusqu'à la sélection de diverses méthodes de filtration comme support de l'adsorption comme un des systèmes d'acceptation le plus universelle: filtres électronégatifs ou électropositifs (Sobsey et Jones, 1979, Joret et d'autres, 1986). La seule exception est peut-être le système du lit fluidisé de la poudre de verre, basé sur le même principe que l'adsorption à filtres de microfibre de verre, utilisé presque exclusivement par des chercheurs français et espagnols.

D'autre part, compte tenu que dans beaucoup de cas le problème ne réside pas dans l'adsorption/élution des virus à un support mais dans leur développement ultérieur, a été l'objet d'une étude immédiate le thème de l'utilisation des lignes cellulaires adaptées au titrage de différentes espèces viriques.

En effet, si le choix d'une seule méthode de concentration (presque toujours adsorption/élution) et d'une - seule ligne cellulaire peuvent servir pour obtenir un index de pollution virale comparable dans l'espace et dans le temps, une étude plus approfondie de la problématique globale est uniquement possible à travers - l'essai de différentes méthodes de concentration (différents supports combinés avec différents liquides d'élu tion), associés avec différentes méthodes de développement. Ceci implique différentes lignes cellulaires, et des méthodes différentes de lecture de l'action des virus: effet cytopatique, immunofluorescence, radioimmu noessai, etc.

La décade des années quatre-vingt, avec un plus grand bagage expérimental autant du point de vue de la méthodologie analytique (concentration et titrage) que de la connaissance étendue des problèmes posés dans - les différents pays par rapport à la présence de différents virus (la poliomyélite ne répresente déjà un - problème important dans les pays les plus developpés), a assisté à une nouvelle avance dans le champ de la virologie des eaux, avance rattachée en grande mesure au changement qualitatif qui représente la possibilité d'étudier les agents responsables de la gastroentérite infantile (Rotavirus) et d'autres agents nouveaux (de Norwalk, de Hawai, du Comtè de Montgomery, etc.) décrits en relation à d'autres types de gastroentérite, et même la découverte que le virus de l'hépatite A (HAV) est un Entérovirus capable de se propager, bien - qu'avec de grandes difficultés, en culture cellulaire. On peut affirmer, en résumé, que, dans les années - soixante, on avait beaucoup d'idées et peu d'information; pendant les années soixante-dix, on acquiert beau coup d'information expérimentale et le principal problème actuel est celui de trouver des idées valables - pour digérer l'information.

A la fin de la décade des années soixante-dix, on a découvert que les Rotavirus se trouvent entre les causes principales de gastroentérites aigües (McNulty, 1978), constituant une cause importante de mortalité et de morbilité infantile dans le monde entier. Les Rotavirus s'excrètent en grand nombre dans les fèces des indi vidus infectés, ayant été détectés aussi bien dans les eaux résiduaires que dans les eaux de surface et sou terraines. Dans quelques approvisionnements on a trouvé des Rotavirus dans des eaux bactériologiquement potables (Keswick et d'autres, 1985; Toranzos, Hanssen et Gerba, 1986).

Quant au HAV, la première recontre de son isolement et sa propagation avec succès dans cultures cellulaires date aussi de la fin de la décade antérieure (Provost et Hillerman, 1979). Cependant, l'isolement primaire de l'HAV a partir de prélèvements d'origine humaine continue à être un processus difficile, long et ingrat. Devant cet énoncé, il ne faut pas s'étonner que l'isolement de l'HAV à partir du milieu aquatique, en combi nant des techniques de concentration comme celles utilisées pour les autres virus entériques et cultures ce llulaires adéquates, soit un champ de travail tres récent, dans lequel, cépendant, on commence à obtenir des résultats encourageants (Sobsey et d'autres, 1985, Sobsey, Oglesbee et Wait, 1985). Il n'existe pas, apparemment, aucun problème pour la recupération des virus ajoutés à l'eau artificiellement, ou à partir d'eaux souterraines suspectes de transmettre des hépatites. Néanmoins, l'application aux eaux contaminées, surtout par les autres virus, pose encore de graves problèmes.

Dans la décade des années quatre-vingt, il faut faire ressortir aussi l'élan coordinateur pour la virologie des réunions bi-annueles du groupe spécifique au sein de l'I.A.W.P.R.C. (International Association on Water Pollution Research and Control) à Pretoria (1982), Amsterdam (1984 et Rio de Janeiro (1986).

Actuellement, malgré les difficultés qui se présentent encore, on voit avec optimisme l'étude de l'incidence et du comportement dans l'eau des virus d'interêt primaire qui sont la cause des maladies de transmission hydrique (HAV, Rotavirus). En même temps, cette nouvelle ère représente une incontestable phase de con solidation dans le développement des techniques pour la récupération des virus entériques humains. Malgré - les problèmes existents dans l'homologation d'informations obtenues par différents chercheurs dans différents types d'eaux, il existe actuellement un niveau de connaissance suffisant pour pouvoir évaluer le pour et le contre de chaque variante de la technologie conventionnelle. Au moins, on est conscient que l'interprétation des résultats doit se faire en termes réalistes, conscient des limites qu'ils supportent, malgrè l'énorme travail qu'ils impliquent. En même temps, l'étude du milieu aquatique (eaux de surface et souterraines, eaux d'approvisionnement, eaux résiduaires), s'étend à celui des boues, des sols, des aerosols et des interphases de tous genres.

En ce qui concerne notre propre expérience, incorporés en marche sur un train à grande vitesse, dans un pays où l'intégration à la Communauté Europénne est encore tres récente, en combinant la recherche à un niveau - d'entreprise d'approvisionnement d'eau avec la recherche de l'université (ce qui implique la possibilité de disposer de la méthodologie mise au point en titrage d'Entérovirus, détection de Rotavirus, phages indicateurs de contamination par virus animaux (Jofre et d'autres, 1986), filtres électropositifs, et de doner les premiers pas vers l'étude de l'HAV en relation avec le milieu aquatique), nous avons réussi à entrer dans - cette nouvelle étape de la virologie des eaux avec de grands espoirs. Espoir de pouvoir détecter rapidement les virus de grande importance sanitaire; espoir de pouvoir améliorer la sûreté du traitement de notre eau face à l'élimination de virus, espoir d'accroître la connaissance de la pollution de nos eaux pour chercher les outils les plus rationnels pour la combattre.

En revenant aux problèmes les plus concrets, nous considérons prioritaire pour nos besoins, en plus du thème Rotavirus et HAV, améliorer les systèmes d'extraction de virus des boues et interphases de différentes sortes, surtout celles que se produisent dans le traitement physico-chimique de l'eau potable, et l'étude du - comportement des virus dans les filtres de charbon. Parmi un contexte d'autres d'une plus grande importance, voilà nos petits défis, peut-être partiellement extrapolables à d'autres services d'approvisionnement d'eau.

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SESSION 9
SEANCE 9

Chairman
Président C. SPREY

- Recent Developments in Data Reading and Data Transmission from Water Meters with Electronic Counting Mechanisms - A Field Test contucted by the Berliner Wasserwerke

  Développements récents dans la lecture et la transmission de données à partir de compteurs d'eau au moyen de mécanismes de comptage électroniques - un essai sur champ mené par le Service des eaux de Berlin

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Discussion

RECENT DEVELOPMENTS IN ELECTRONIC DATA READOUT AND AUTOMATIC REMOTE READING OF WATER METERS WITH ELECTRONIC COUNTING MECHANISMS - A FIELD TEST CONDUCTED BY THE BERLINER WASSERWERKE -

Dr.-Ing. Klaus Beyer

Berliner Wasserwerke, Hohenzollerndamm 45, 1000 Berlin 31,
Federal Republic of Germany

ABSTRACT

Water supply services require among other things reliable information on water consumption in defined areas to enable efficient planning and effective control and management. Both the reading of water meter values and their transmission into electronic data processing systems for billing is today still mainly carried out by human labour.

The possibility to manufacture water meters designed for electronic data reading and thus remote transmission, at reasonable cost, rests on an exchange of the mechanical counting mechanisms in the customary water meters for an electronic capsule.

Such an electronic capsule has now been developed by two German manufacturers of water meters at the request of the Berliner Wasserwerke. The Berliner Wasserwerke helped finance the development costs. Japan is the only other country where similar products exist, to my knowledge.

Since mid-1987, the German Postal Authorities offer (presently limited to a five-year trial period) in 11 cities in the Federal Republic of Germany including Berlin (West) the new "TEMEX" service for EDP-controlled readouts of alarm signals and meter values, to name just two examples, over conventional telephone cables and using the existing infrastructure areawide for private homes and industrial buildings. These data are placed at the disposal of the user, as for example the water supply service, in form of a packet. The information can then be automatically entered into the computer system of the respective enterprise for further processing.
Beginning in May 1987, the Berliner Wasserwerke plan to conduct a one-year field trial with 50 water meters fitted with electronic counting mechanisms.

KEYWORDS

Electronic readout; automatic remote reading; remote data transmission; water meters with electronic counting mechanisms; TEMEX; LCD; weight and measuring law, data protection.

INTRODUCTION

Water supply services require for economic planning, supervision and administrative control reliable data on consumptions. Water meter reading and transfer of current readings and, where applicable, the identification number into electronic data processing units for billing are mainly carried out by employees of the public utility companies.

Long-term studies have revealed that the cost of meter reading is on the increase. This increase results from:

1. Rising cost of labour,
2. Expansion of residential areas and thus longer traveling distances for meter readers,
3. Increasing number of customers away from home; in some regions this rate amounts to some 25 per cent.

Automatic remote reading of water meters would solve these problems. The method can, however, be equally applied to optimization of building structures still in the planning stage (e.g. pipeline systems and pumping stations) and for operation of the pipe network. Both business men and technicians are no doubt interested in the implementation of automatic remote readout systems.

For the design of systems based on automatic remote readout, water supply service companies must take into consideration the following:

1. Conformance to the Federal Weight & Measuring Law, when the data are used for billing,

2. Restrictive legal requirements on data protection; in the Federal Republic of Germany and Berlin (West), the laws relating to protection of the privacy of personal data must be observed for remote readout of private installations.

3. Registration with the German Postal Authorities; an official permit for the "intelligent" water meter is granted by the "Fernmeldetechnische Zulassungsstelle der Deutschen Bundespost" in Saarbrücken (ZZF).

4. Assurance of reliable data transmission.

5. Economy of the overall system.

The above-stated points need to be explained in more detail. In order to meet the requirements of the Weights and Measures Department, the water meter must be capable of verification and must be so designed that it cannot be manipulated from the outside (e.g. through use of magnets). Upon completion of the remote reading process, the last recorded value must be stored.

In the Federal Republic of Germany, including Berlin (West), the period of validity for verification is 8 years. Within this period, the deviation of the measured values recorded by the water meter may not exceed the limits of error in service. This requirement applies both to the mechanical water meter and the water meter with electronic counting mechanism.

The restrictive legal requirements on data protection are defined in Berlin (West) in the "Law on execution of the cable pilot project Berlin (Cable Pilot Project Law - KPPG) dated 17 July 1984". For transmission of consumption data, § 53 KPPG applies. Paragraph 3 states the following:

"The establishment of remote-measurement and remote-control services is only permissible when the subscriber is able to recognize, when the service is made use of as well as the nature of the service and when the subscriber can switch off the service whenever desired, provided such disconnection is not in contradiction with the purpose of the contract. When in doubt, disconnection of a service shall be construed as withdrawal of the consent."

For the "Berliner Data Protection Concept", the Berliner Wasserwerke have determined, in close collaboration with the data protection official of the Land Berlin, that the remote readouts will be counted. The recorded value of the always last electronic readout and/or remote readout will, in addition, be stored. These values, access value and latest readout value can be called up by the customer at any time.

The official permit for the end product (i.e. the terminal equipment - in this case the water meter with electronic counting mechanism ((EWM) from the Postal Authorities, will be granted only when it has been shown that feedbacks from the EWM into the telephone network of the Postal Authorities or current drainage from the network are not possible.

The reliability of data transmission must be ensured through a reliable electric power supply and secure data transmission. That all of the above-stated requirements are technically feasible has been demonstrated in numerous publications and also at the most recent IWSA Congresses.

The economy of the overall system can be achieved with a reasonably priced water meter with the possibility of remote transmission and a cost-effective remote transmission itself.

INTERNATIONAL ACTIVITIES IN THE FIELD OF REMOTE TRANSMISSION OF WATER CONSUMPTION DATA

At the recent IWSA Congresses, trials conducted with remote water meter read-out systems in several industrialized nations were also discussed. The conclusion was drawn that remote water meter reading utilizing existing telephone lines, cable television networks and existing cables for electric power supply is no longer a technical problem. Large-scale conversion to this system has however not yet taken place because the economy of the system is not readily recognizable or owing to administrative obstacles. But world-wide commercial application of remote water meter readout systems will only a question of time through use of new technologies.

Restricted use of remote readout is practiced both by the Société Lyonaise des Eux, Paris, and the Compagnie Générale des Eux, Paris. In Great Britain, a new system for remote reading of water meters is currently being tested by the local Gas-, Electric Power-, and Waterworks. In the Netherlands, four thousand water meters are read out by way of a new American remote transmission process. From the USA, too, remote read-out via telephone lines and also over short distances, e.g. from external house walls, are reported. Dr. Onoda reported on the development of telemetry in Japan at the 1982 IWSA Congress. The Japanese Post Office Department decided as long ago as in 1978 at a conference to use the telephone network for remote transmission of consumption data. Dr. Onoda reported further on tests conducted with conventional water meters with pulse output and the development of water meters with electronic counting mechanisms. He introduced this new water meter at the last IWSA Congress in Rome in 1986. He reported further on field tests carried out on 12 locations in Japan using over 56,000 water meters of different design.

In Europe, efforts are under way to agree on standardization of the different systems even at this early stage, before national regulations result in international obstacles. Towards this end, a working group consisting of users (EUREAU) and manufacturers (AQUA) has been formed.

WATER METERS WITH ELECTRONIC COUNTING MECHANISMS (EWM) AND ELECTRONIC READOUT DEVICE (ERD)

One possibility to manufacture a system suitable for electronic readout involves replacement of the mechanical counting mechanism of the customary water meter with an electronic counting mechanism in form of a capsule (Fig. 1).

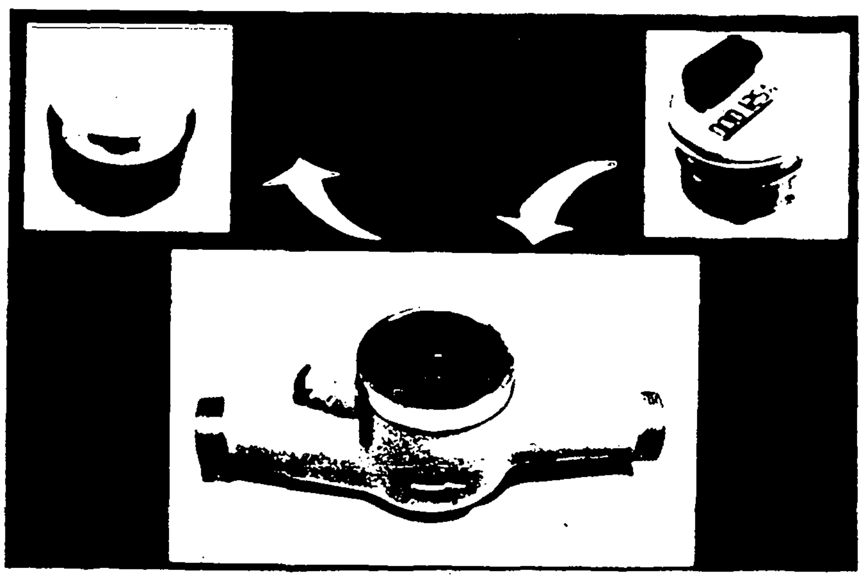

Figure 1. From the water meter with mechanical counting mechanism to the water meter with electronic counting mechanism.

Housings not expressly designed for use with the new water meter system must be adapted, e.g. the measuring wing changed. In principle, the impeller-type meter with immersed counting mechanism is converted into one with "dry" counting mechanism.

The best choice would be a simple transmission system that permits direct electronic reading or automatic remote readout. The intermediate step, processing the impulses recorded via an impulse contact maker in an additional unit and than transmit it, could then be dispensed with. This new concept is already being tested in Japan (Fig. 2).

Reliable operation and simple handling are requisite to utilization of water meters with electronic counting mechanisms. To achieve this aim one must do without external power supply to the water meter via cable and use batteries instead. Care must be taken that the required performance is adequate to ensure reliable operation of the water meters for the entire period of validity for verification including an appropriate reserve.

Another variant would be the battery-buffered meter switching device. . In this case, the impulse of the readout would have to be sufficient to recharge the battery once again. To ensure reliable operation, an electronic readout of data using the readout device or via remote reading would have to be taken periodically, e.g. once a year.

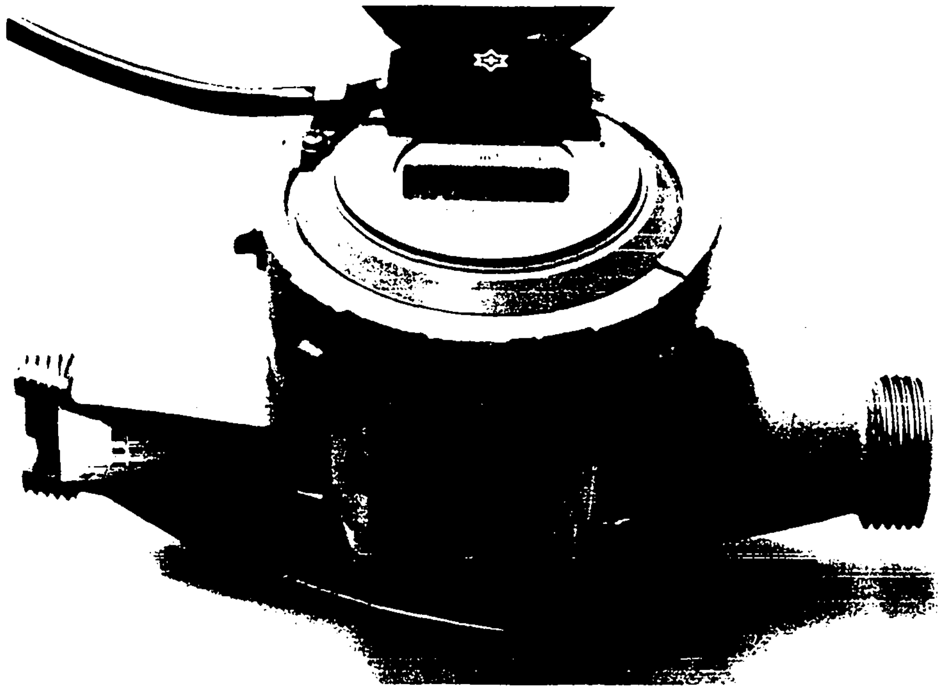

Figure 2. Japanese water meter with electronic counting mechanism designed as a capsule

At this time, we do not know whether the electronic counting mechanism in form of a capsule can be manufactured so cheaply that it can be discarded or reused after the batteries have been replaced. Which one of the two types will be able to assert itself will depend on the quantities in which the devices will be used.

In the case of bulk water meters, the mechanical counting mechanism is likewise replaced with an electronic device and is thus integrated in the water meter as capsule. A similar product, however with a mechanical roller counting mechanism in form of a capsule, is already available on the market (Fig. 3).

Figure 3. The bulk water meter with mechanical roller counter designed as a capsule (here: Woltmann meter type WP 50 mm COSMOS T).

Since both the bulk water meter and the domestic water meter (Fig. 4) are designed with one electronic capsule each, simple electronic readout or automatic remote readout is also possible for combination water meters.

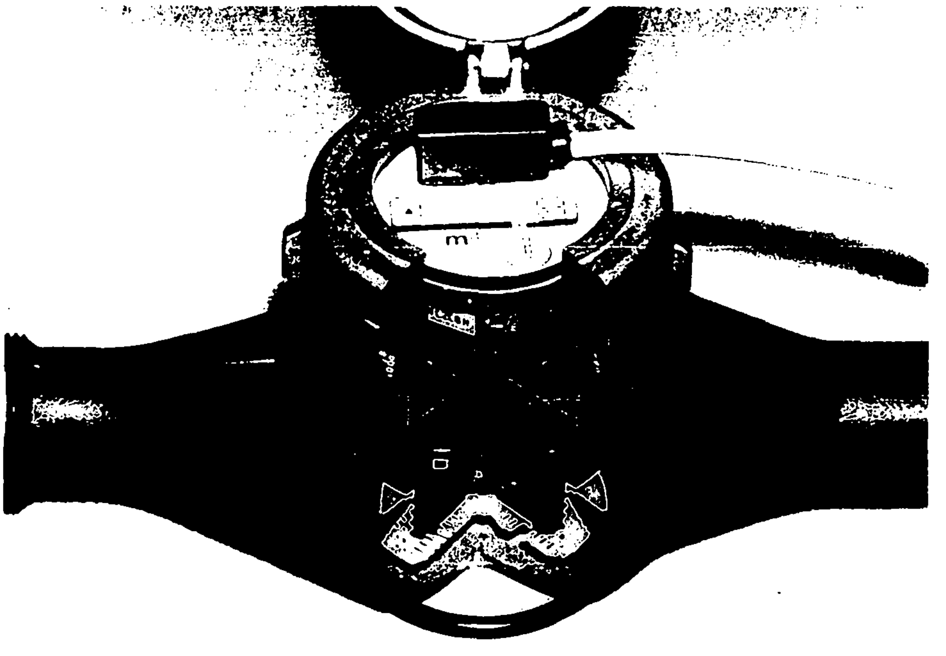

Figure 4. Domestic water meter with electronic counting mechanism (here: multi-jet impeller-type meter type MT Q_2 2,5).

Older bulk or domestic water meters which cannot be converted can instead be fitted with a reed contact pick-up which is mounted on the mechanical part of the counting mechanism. The electronic capsule which serves as impulse counter electronic is attached outside the water meter.

The concept on which the field test carried out by the Berliner Wasserwerke is based offers three possibilities for electronic readouts of EWM:

1. direct readout at the EWM with an electronic readout device (ERD),
2. readout with ERD at the data interface which is installed either on the manhole cover or on the property boundary line.Cable lengths of approx. 15 m are permissible.
3. Remote reading making use of TEMEX.

On the EWM itself, the customer can call up several data on a LCD indicator (Fig. 5). This system offers the possibility to indicate 9 digits, the direction of flow and the loading condition of the battery. A 9-digit permanent display reflects the current readings. The arrow, indicating "Direction of flow forward", serving as flashing "test star" is also permanently displayed. The function "Direction of flow reverse" is likewise shown by an arrow. The battery symbol is only visible when a preassigned limit value of the loading condition is fallen below.

An electronic switch is integrated into the electronic counting mechanism which is actuated by passing a small magnet across the cover glass. In response, the following functions occur within approx. 7.5 seconds in sequential order:

1. Performance test: All existing segments of the display are indicated. Following completion of the performance test, the display indicating the arrow pointing in the direction of flow is uncoupled from the remaining functions and can be called up at any time owing to the impulses actuated by the water flowing through the water meter. This way the assurance is given that the capability of the water meter to be called up within the following six seconds during which no current reading is visually displayed.
2. Erasure of display
3. Display of the stored meter reading from the last electronic readout.
4. Display of the number of accesses and
5. Flow rate display. The flow rate is obtained through integration within that period of time during which function 4 is displayed.

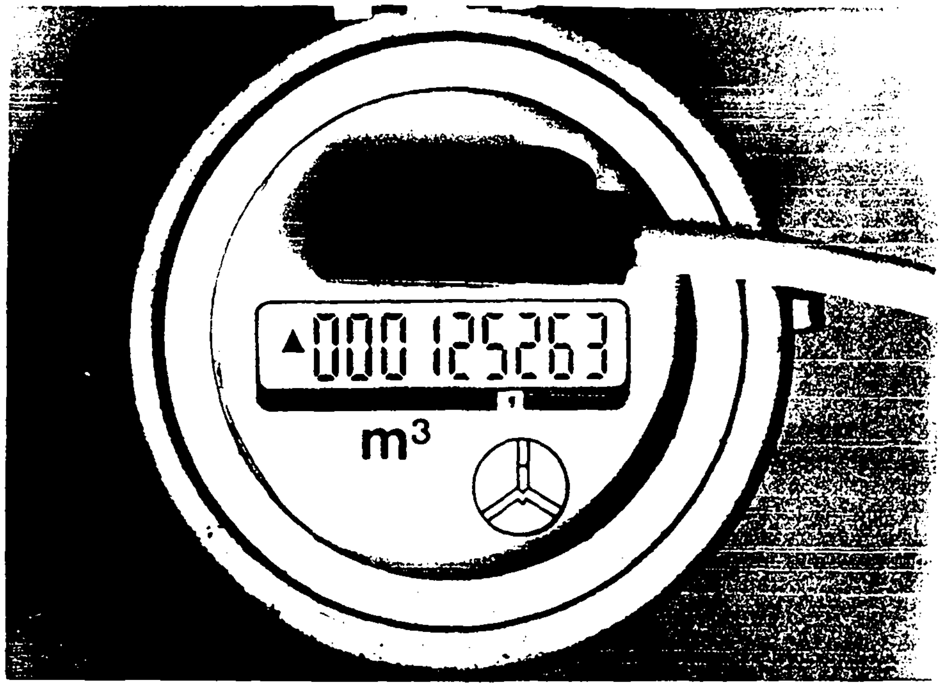

Figure 5. LCD indicator of the water meter with electronic counting mechanism.

For the time being, use of an electronic readout device (ERD) in the form of a programmable small computer with real time generator (date and time), data memory and interface is planned. Once the connection with the EWM has been established, the data are read out in sequential order:

1. Current reading (9 digits),
2. Meter identification number (7 digits),
3. Flow rate (4 digits in cu m/h),
4. Access number (3 digits) and
5. Status (e.g. battery loading condition (1 digit)).

These data are as a general rule supplemented by the date and the time from the real time generator of the readout device and stored as complete data record. The ERD is so designed that in addition to the readout and storage of data there is the possibility to permanently display individual values by pushing a key.

The general concept presented here incorporates the technical requirements for simple remote data transmission. Concrete statements on possible measures of rationalization in the operations of public utility companies can, however, at this time not be made.

REMOTE DATA TRANSMISSION IN THE FEDERAL REPUBLIC OF GERMANY AND IN BERLIN (WEST)

The TEMEX-Service of the German Postal Authorities

The German Postal Authorities are searching for ways and means to exploit the existing telephone infrastructure, such as copper cables and other technical equipment, more fully. Towards this end, the Postal Authorities will offer beginning the middle of 1987, a new service - TEMEX (Telemetry Exchange) to begin with within the scope of a 5-year field test. The field test of the Postal Authorities will for the time being be restricted to 11 cities in the Federal Republic of Germany (Fig. 6).

The cities are: Hamburg, Hanover, Osnabruck, Munster, Dortmund, Cologne, Andernach, Mannheim, Kornwestheim, Stuttgart, and Berlin (West). The cities of Hanover, Osnabruck, Dortmund, and Andernach will not participate in the transmission of water consumption data within the scope of the TEMEX field test.

With the introduction of the new service TEMEX, the free capacities of the existing telephone network of the Post, utilized to full capacity at the most for several minutes at a time or a few hours of the day, are utilized. Thanks to the state-of-the-art microprocessor technique it is nowadays easy to use telephone lines not used to capacity for remote data transmission without interfering with the telephone service.

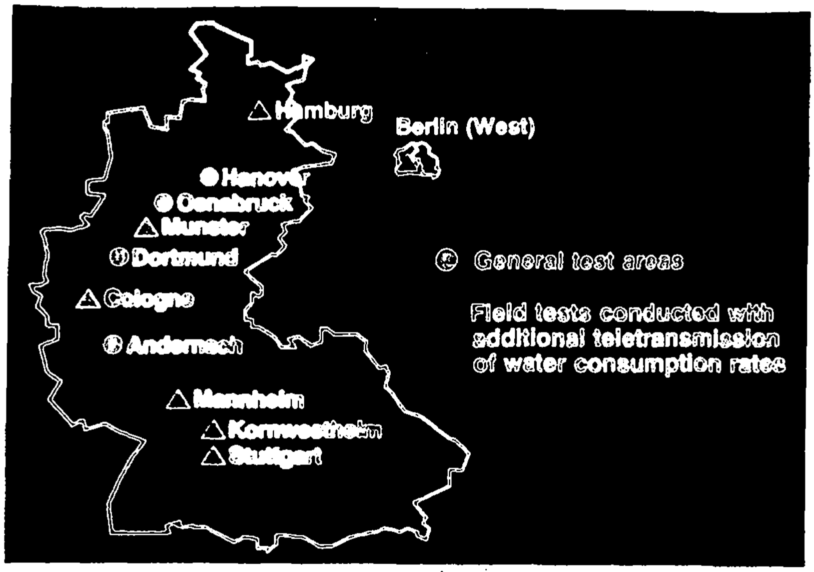

Figure 6. The regions of the Federal Republic of Germany in which TEMEX field tests are scheduled.

The TEMEX-Service of the German Postal Authorities opens up new solutions for remote transmission of information as well as the chance to utilize hitherto unexplored services.

The general term telemetry comprises the terms remote supervision (remote indication and remote measuring) and remote control (remote switching and remote adjustment).

Figure 7 shows a survey of the general TEMEX system, broken up into three areas:

1. the TEMEX installation at the subscriber's home,
2. the TEMEX-System of the German Postal Authorities and
3. the TEMEX control centre of the offeror (e.g. the water supply service).

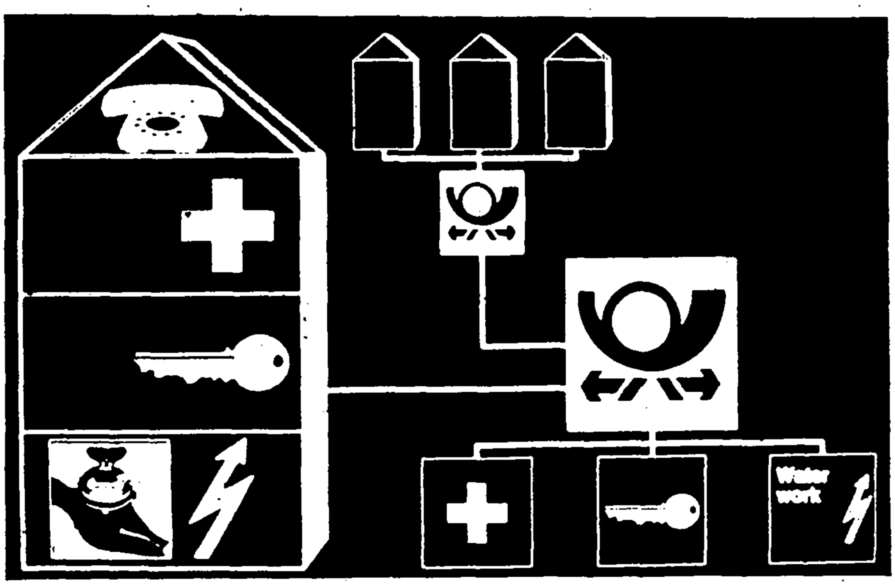

Figure 7. Automatic remote data transmission utilizing TEMEX.

All three fields of application are part of a public telephone service network. The installations in the private sector are governed by similar rules as those of the telephone service regulations, according to which private telephone subscriber sets must be accepted by the German Postal Authorities. This means that only officially approved terminal equipment units may be connected to the network of the German Postal Authorities.

Remote transmission of data from the terminal equipment (e.g. water meter) to the TEMEX recording device (TNA) so installed that it is protected from the weather (e.g. basement), takes place within the sphere of the TEMEX user, for example the customer of the water supply service (WVU). He must not necessarily be a subscriber to the telephone service. The information is transmitted from the TNA to the TEMEX centre (TZ) over the telephone connection line. The frequency range in which the TEMEX signals are transmitted lies within the Simplex operation (transmission of information in one direction) between 34 kHz and 46 kHz and in dual operation (transmission of information on both directions) between 34 kHz and 62 KHz. Since telephone conversations are as a general rule transmitted in the frequency range of 300 Hz to 3400 Hz, the telephone service is not in the least affected by the overlaid TEMEX channel.

Special switching ensures that remote transmission of information takes place even when a subscriber is taken off the telephone (e.g. disconnection as a result of unpaid telephone bills).

At the TEMEX centre, the data packets are allocated to the appropriate private remote control centres (FWLSt) of the TEMEX offeror.

The TEMEX service offered by the German Postal Authorities is a "24-hour service". The entire transmission system, including the TNA, is continually checked for smooth performance so that a maximum degree of security can be warranted by the German Postal Authorities.

The TNA can comprise one or several TEMEX interfaces (TSS) which are connected to the respective terminal equipment such as e.g. water meter, alarm signal etc. One differentiates between time-critical and time-uncritical TSS. The Post offers six interfaces to meet as many requirements as possible (Fig. 8). The interfaces differ from one another by the number of telegrams to be transmitted each month and the data quantity per telegram. Only two of these interfaces are of interest to the water supply service, namely interface TSS 14 and interface TSS 14.

Model	Frequency (max. Value/Month)		Fee DM monthly
	Number of "telegrams" time critical	Number of "telegrams" not time critical	
TSS 11	200		3.-
TSS 12	200		3.-
TSS 11+12	every 200		4.50
TSS 13	2000		15.-
TSS 14		5	3.-
TSS 15a	200	40	12.-
TSS 15b	200 random		18.-

Figure 8. Performance and anticipated rates for TEMEX user connections

Time-critical interface TSS 13

Interface TSS 13 permits transmission of polyvalent commands and signals. These may consist of several bivalent or also a combination of uni- and bivalent commands and signals as e.g. the transmission of an alarm with simultaneous transmission of the relevant measured value. At this interface, the time of transmission is determined and controlled from the measuring point (e.g. EWM).

Interface TSS 13 permits transmission of 2000 data in each calendar month.

Non-time-critical interface TSS 14

Interface TSS 14 receives and/or transmits remote control data that is not time-critical (e.g. consumption rates). The time of transmission is determined by the user and controlled by the Post within certain time tolerances.

The information called up from TSS 14 can be put for up to 4 days in temporary storage at the TEMEX centre. The capacity of the TEMEX system permits remote transmission of several thousand data within only a few hours. For individual orders, the German Postal Authorities promise that in about 90 % of all cases the time required for calling up information from TSS 14 to receipt in the control centre does not exceed one minute.

Transmission frequency at interface TSS 14 has been fixed at five telegrams for each calendar month. The user can obtain the date and time of a consumer reading in advance from the German Postal Authorities in connection with an omnibus and/or time-related order. In case of the time-window function, advance information can be obtained via the respective remote control centre.

International standardization of interfaces

Growth of information and communication technology continues unchecked on a world-wide basis. It is therefore not surprising that e.g. the European Economic Community gives priority to the field of communication technologies. Of primary concern is here standardization of information and communication techniques. In 1984, the Commission of the European Economic Communities recommended for example the following European standardization process:

"The Commission recommends that the administrators of telephone communication networks shall ensure that as of 1985 all new services shall be implemented on the basis of a joint standardized process, particularly so in the member states so that compatible services will be offered in Europe, which take into account the work progress in CEPT, CEN/CENELEC, CCITT and ISO."

Standardization in the field of telephone communication is requisite both for international remote data transmission and for economical manufacture of equipment to ensure compatibility of the various systems components with the transportation connections. The International Standards Organisation (ISO) fully supports the recommendations for harmonization of the international advisory committee of the telegraph and telephone service (Comité Consultatif International des Télégraphique et Téléphonique - CCITT). The results are evidenced in national standards.

In our particular case, the German Postal Authorities have directed the companies engaged in the development of the TEMEX technique to adapt the design of the interfaces to the CCITT recommendations. Thus it will also be technically feasible to introduce this service also outside the Federal Republic of Germany and to communicate with one another. The international manufacturers will therefore be able to connect their equipment to the TEMEX network of the German Postal Authorities without problem.

Availability of the TEMEX System

The availability of the general TEMEX system amounts to more than 99.85 %, in accordance with the German Postal Authorities. Restart of the system following software failure or power breakdowns commences in 95 % of all cases in under 90 seconds.

Rates

The German Postal Authorities charge a flat monthly rate for the interfaces, viz. DM 15.00 per month for TSS 13 for 2000 transactions and DM 3.00 per month for interface TSS 14 for 5 transactions.

In addition, there is a single charge in the amount of DM 65.00 for connection of each interface and a monthly fee for use of the transmission lines between the TEMEX Centre and the utility service's control centre in the amount of DM 150.00 per month. Discounts are being granted by the German Postal Authorities to the participants in the field test. A further reduction of the connection fees is possible when several parties share one TNA.

The public utility companies in Germany hope to persuade the German Postal Authorities to lower the cost for this service for the field of consumption rate recording. Intensive negotiations are under way. The Post would stand to benefit from this scheme in as much as it would then be possible to build and implement a closely knit TEMEX network throughout the country. This would also help potential users to decide in favour of data communication via TEMEX.

FIELD TEST CONDUCTED BY THE BERLINER WASSERWERKE

The Berliner Wasserwerke have scheduled for the time being a one-year field test to start in May 1987, using water meters with electronic counting mechanism (Fig. 9).

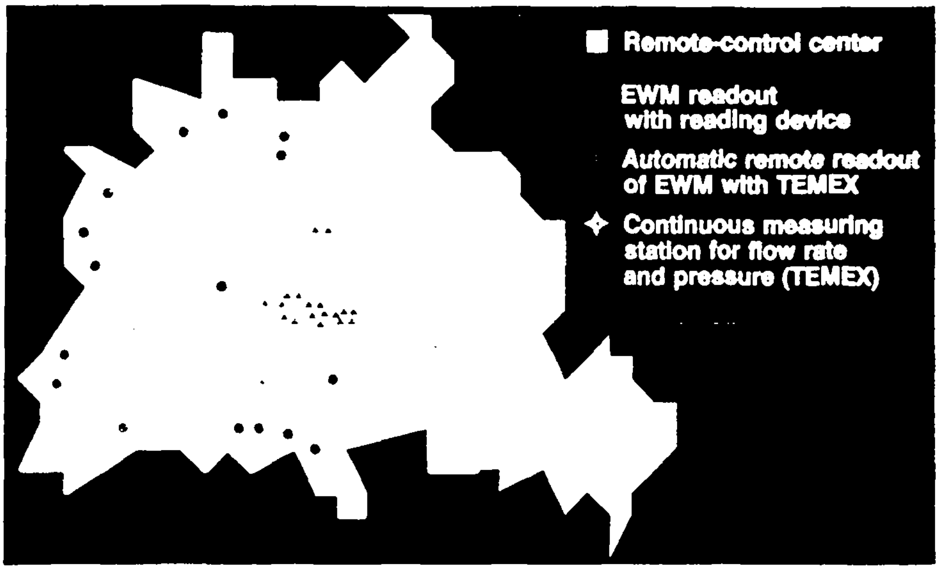

Figure 9. Location of water meters with electronic counting mechanisms in the field test to be conducted in Berlin (West).

Development of the "intelligent" electronic capsule undertaken on the initiative of the Berliner Wasserwerke has by now been completed. 50 water meters with electronic counting mechanism will be used in the field test (Fig. 10). On 18 of these water meters remote transmission utilizing the new TEMEX service of the Federal Postal Authorities will be tried out. The remote control station for this purpose has been set up in the metering system of the Berliner Wasserwerke.

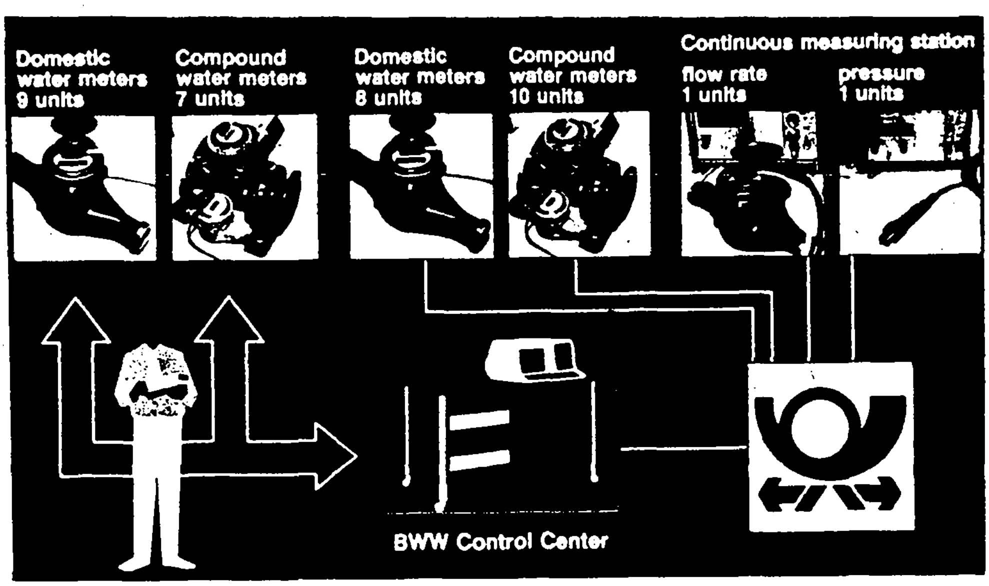

Figure 10. Data transmission during field test conducted by the Berliner Wasserwerke.

The remaining EWMs will be read out with an ERD on location by employees of the Waterworks.

The 50 EWMs are comprised of 18 domestic water meters and 16 compound water meters. The units are installed either in basements or manholes.

Within the scope of the field test conducted by the Berliner Wasserwerke it is further planned to record measured data on the present operating condition of the pipe network and to transmit these recordings to the control station via the TEMEX service. For this purpose, one measuring point will be equipped with one water meter and one pressure sensor each and connected to one time-critical interface TSS 13 with 2000 telegrams/-month. It is planned to transmit maximum, minimum and mean values for pressure and flow rate by the hour via an additional electronic device. These values would form the basis for pipeline network calculations and planning. They can, however, equally be used for optimizing the economy of the operations of the Waterworks.

Remote control centre

The remote control centre offers the opportunity to call up data either via TEMEX or the ERD. For the purpose of the field trial, perhaps later on in general, an address/meter identification number file of the subscriber will be stored in the personal computer in the remote control centre. This way, the consumption values can later on be supplemented with customer-specific data for internal use or invoicing. The stored data can be further processed at any time. They can for example be printed out in the form of tables which contain the data received either via TEMEX (Fig. 11) or via the readout devices.

Daten für Rechnungslegung über TEMEX

Datum	Uhrzeit	Zählerstand	Anzahl der Zugriffe	Verbrauch seit der letzten Ablesung	Batteriezustand	Zähler-ID-Nr.	Adresse	Kunden-Nr.
		m^3		m^3				
26.01.87	01:07 10	0537.5	011	1270	0	0305293	31-Nassauisch 64	3701-0549 [illegible]
26.01.87	01:07 11	712.7	012	186	0	2560372	51-Herbststr 35	4170-0054 [illegible]
26.01.87	01:07 12	4170.3	011	1845	0	7034289	33-Speisstr 22	1450-3398 [illegible]
26.01.87	01:07 13	634.1	013	165	0	4516789	37-Juttastr 12	7137-5987 [illegible]
26.01.87	01:07 14	1178.0	010	389	0	6548763	49-Sodenstr 29	2654-7463 [illegible]
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.

Figure 11. Example for consumer data evaluation

The data sets contain date and time of the readout, current meter reading, number of accesses, consumption since the last readout, battery loading condition, meter identification number and address. The data sets used for printed tables are supplemented with the appropriate addresses and customer numbers from the data memory of the PC at the remote control centre.

The data from the permanent metering points are also stored for further processing. The data can however also be immediately printed in the form of tables or as a graphic presentation (Fig. 12). Subdivision of abscissas and ordinates can of course be handled with the freedom allowed by the individual system.

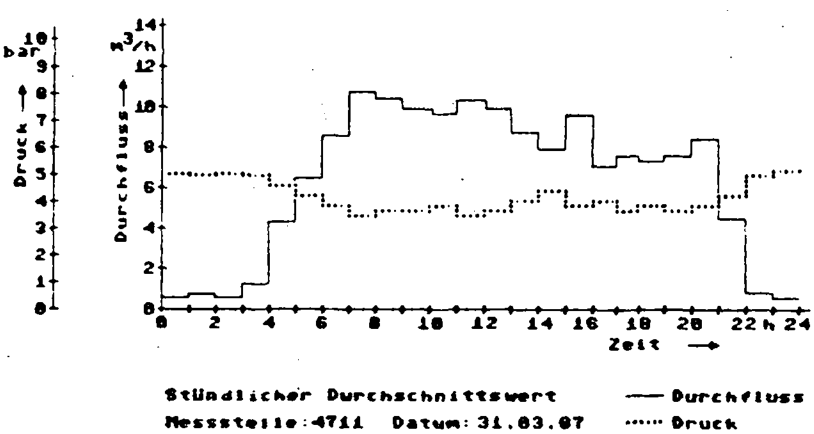

Figure 12. Flow-rate and pressure values taken at the permanent measuring point.

OUTLOOK

For the future (Fig. 13) a data network is conceivable within the operations range of the Berliner Wasserwerke in which the data recording station assumes a central function in metering systems. Here the pressure and flow-rate values are recorded on the one hand, and the consumption data and meter identification numbers following scheduled replacement of the meter on the other hand, as well as the test values Qmin, Qt and Qmax registered at the time the meter is certified, transferred to the mainframe and a test protocol prepared. Input of consumption data from the ERD is possible in each terminal with interface and thus also in the terminal used for selling water.

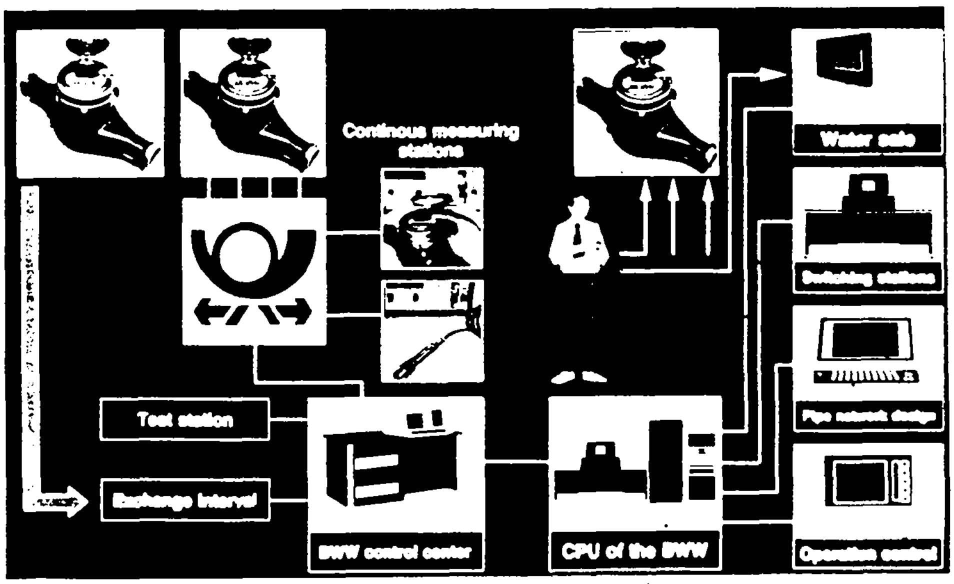

Figure 13. Future model of a data network.

The departments pipe network operation, pipe network calculation, sales and invoicing, the radio control centre and the electric control centres of the Waterworks can at any time call up the data stored in the mainframe and use them for individual evaluations.

Data transmission, such as for example consumer data, will play in general a much more significant rôle in the future than it does today. In view of the many diverse possibilities offered by TEMEX, the Postal Authorities are predicting already at this early stage that eventually at least 10 % of all telephone users will avail themselves of this new service; and this despite the fact that there are still some unsolved problems - in particular with regard to meter readout. Thanks to the commitment shown by a major German maker of bulk water meters and a German manufacturer of domestic water meters in developing "intelligent" water meters with electronic counters, there exists, at least in the Federal Republic of Germany, a system for remote data transmission and remote readout of water consumption data, which will in the near future also be provided with the official approvals by the Postal Authorities (ZZF) and the PTB and which will in addition satisfy the requirements of the data protection law.

In particular countries with high costs of direct labour will be inclined to adopt such a romote data transmission system, rather than countries where manhours are less expensive. The rationalization effects possible with this system should, however, not be overestimated, since for the time being no TEMEX-compatible telecontrol communications terminals are as yet available. For specific applications, such as for example network and systems supervision, TEMEX will however be of great help.

First economic assessments made by special customers that practice remote readout of consumer data on a monthly basis using their own personnel and under utilization of TEMEX show that the TEMEX system is in fact superior to the conventional one. The current findings which are for the time being restricted to this one area of application should encourage both supply undertaking utility companies both at home and abroad to get acquainted with this new technology and consider its application.

UNE APPROCHE GLOBALISEE A LA TELEMETRIE - NORTH WEST WATER AUTHORITY - UN PROJECT DE TELEMETRIE REGIONALE

P. Bland*, J. C. Townend**

*North West Water Authority, Warrington, England
**Kennedy and Donkin Systems Control Limited, Manchester, England

EXTRAIT

Il est estimé que les dix authorités responsables de la fourniture d'eau en Angleterre et au Pays de Galles investiront au cours des prochains quatre à cing ans plus de £130 millions en telemetrie et instrumentation, controle et automatisation. Ce document a pour buet de décrire un tel projet, la telemetrie regionale à la NWWA. Ce projet de'bouchera sur l'establisement d'une infrastructure d'operations et de controle cruciale au bon fonctionnement de l'authorité dans la prochaine décennie et après. le projet permettera dans un premier temps le controle de 1200 points d'operations d'importance primondiàle á travers un réseau de trente quatre centres de controle de districts et trois centres de communications de zones à un côut total de £16.5 millions (prix 86 - 2 eure tremestre). Malgré le fait que le système choisi sera un facteur déterminant dans l'élaboration du projet, le défi majeur à relever n'est pas la téchnologie elle-même mais le fonctionement et l'utilisation éfficace de la téchnologie mise en place. Trop souvent dans le passé une attention insuffisante à été, portée à la definition et la consideration des besoins de l'utilisateur et à la formation du personnel à être affecté à la gestion du projet. L'importance de ces facteurs à eu comme resultat une emphase considérable a là planifaction du projet, la participation des utilisateurs la definition de la formation nécessaire pour les utilisateurs et la qualité en génerale.

AN INTEGRATED APPROACH TO TELEMETRY - NORTH WEST WATER AUTHORITY - A REGIONAL TELEMETRY SCHEME

P. Bland*, J. C. Townend**

*North West Water Authority, Warrington, England
** Kennedy and Donkin Systems Control Limited, Manchester, England

ABSTRACT

The Water Industry in the UK today operates in an environment of almost continuous change. The requirements of meeting strict cash limits imposed by Central Government whilst satisfying both national and EEC Standards for both level and security of service, quality of water supply and environmental pollution controls are set against a background of possible privatisation of the industry. As one means of meeting the challenge of controlling the many changes being imposed on the industry, many of the UK Water Authorites are planning large scale investments in operational decision support systems. The basic building block of many of these systems is the provision of operational data via telemetry.

It is conservatively estimated that the ten Water Authorities in England and Wales will collectively invest over £130m on telemetry, instrumentation, control and automation systems in the next four to five years. Information and automation technologies are seen as having a key role in enabling the industry to control the changes and challenges over the next decade towards the year 2000. This paper describes one such system, NWWA's Regional Telemetry Scheme. This scheme will provide an infrastructure of operational monitoring and control crucial to the Authority's operation for the next decade and beyond. Although the system design selected will be a critical factor in ensuring the success of the scheme, the major challenge presented by the scheme is not that of the technology involved but of making the technology work effectively. Too often in the past insufficient attention has been paid to the definition and validation of user requirements, to training requirements and to the process of project management. The importance of these factors was recognised and considerable emphasis was placed on the planning of the scheme, of user involvement, definition and training of system users and quality assurance.

KEYWORDS

Telemetry, SCADA, user requirements, project management, training, alarm management systems, ICA, site audit, quality assurance.

INTRODUCTION

Background

The 1973 Water Act of Parliament (Parliament 1973) created the present structure of ten Regional Water Authorities and 30 private water companies in England and Wales. Each Authority has responsibility vested by Parliament for the management of water supply, sewage treatment and other related functions.

North West Water Authority (NWWA) serves a population of over 7 million people covering an area of 14,500 square kilometres of the north west of England. It provides 2,600Ml of water per day to domestic and industrial consumers through a network of 38,000km of water mains and is responsible for 30,000km of sewers and 630 sewage treatment plants. For an operation of this size and complexity it is essential that operational management has rapid access to accurate information on the many thousands of operational sites in order to provide an effective and efficient service to its consumers.

The Water Industry in the UK today operates in an environment of almost continuous change. The requirements of meeting strict cash limits imposed by Central Government whilst satisfying both national and EEC standards for both level and security of service, quality of water supply and environmental pollution controls are set against a background of possible privatisation of the industry. In addition the need to replace ageing assets of sewers and water mains and the desire to make the most effective use of information technology with the decreasing cost in real terms of electronics and communications technology are also factors influencing change in the industry.

NWWA along with the other Water Authorities have had long experience of the utilisation of telemetry and instrumentation, control and automation (ICA) systems to assist with the management of their assets. However, in contrast with the other major national utilities of electricity and gas, the water industry has not found it necessary to invest in wide-scale telemetry systems. This situation is now rapidly changing and many of the UK Water Authorities are planning large scale investments in operational decision support systems. The basic building block of many of these systems in the provision of real-time operational data and control via telemetry and ICA systems.

All the Water Authorities are responsible for a large number of operational plants scattered over a wide geographic area. Traditionally the Water Authorities have been dependent on daily visits to many of their sites to determine the basic operational information required for current operations and for the collection of archived data on which analysis for longer term planning needs are dependent.

Telemetry is being recognised as the key to the acquisition of this data and is the basis on which comprehensive operational management systems will be built.

It is convervatively estimated that the ten Water Authorities in England and Wales will collectively spend over £130M on telemetry and ICA systems in the next 4 to 5 years.

It is considered that information and automation technologies will have a major influence on the capacity of the industry to control the changes and challenges facing the industry over the next decade towards the year 2000.

NWWA - Regional Telemetry Scheme

NWWA was formed in 1974 as a result of the 1973 Water Act. Prior to that date the industry in the North West had been fragmented and NWWA took over from 248 predecessor bodies. As a consequence NWWA was presented with the task of managing all related water supply and treatment activities and as a result the opportunity was available for the first time to manage the water cycle as a total system.

Over the past ten years NWWA has invested in excess of £90 Million in ICA equipment. This investment has generally been justified on a project-by-project basis in terms of its operational benefit in controlling that particular plant or group of plants. This approach has led to the installation of many separate and different systems. Currently there are more than 20 different computer-based data acquisition and control systems installed. These many varied and dispersed facilities are "stand alone" and cannot be integrated without major hardware and software modifications. The majority of this equipment was purchased on a "lowest capital cost" basis and cost of ownership was not generally taken into account. This has led to many of the installations being of poor quality, poor reliability, limited facilities and importantly, incapable of expansion, upgrading and integration.

In late 1984 the Board of NWWA confirmed that telemetry, telecontrol and ICA techniques were an essential part in managing the water cycle and approved the implementation of a region-wide data acquisition system - the Regional Telemetry Scheme.

This initiative was to be developed in four phases:-

- Phase I — Monitoring and supervision of key operational installations. The selection of sites was to be determined by assessing the impact to the customer if the process failed.
- Phase II — Reduction in operating costs by use of plant optimisation e.g. energy management, pump scheduling etc.
- Phase III — Integration of systems on a functional basis to link operationally associated groups of sites.
- Phase IV — Integration of systems on a regional basis to allow free interchange of operational data to assist in the system management of the total water cycle.

Phases 1 and 2 are to be implemented at an estimated cost of £16.5 Million (Q2 - 86 prices) with the system so designed to enable Phases 3 and 4 to be completed with minimum further investment.

This scheme is believed to be the first in the UK to be conceived on an integrated Regional basis and will provide an infrastructure of operational monitoring and control crucial to the Authority's operation for the next decade and beyond.

Frequently schemes of this nature have not met their full potential for a variety of reasons.

TABLE 1 - Problems Experienced with Implementing Past Systems

PROBLEM	RESULTS
User requirements not clearly stated.	Installed system not meeting operational need.
User requirements not adhered to in design.	Installed system not meeting operational need.
Poor equipment installed at lowest capital costs.	Unable to develop, limited facilities, poor reliability.
Lack of training provided.	Operator unable to maximise system facilities.
Insufficient spares/maintenance.	Long down times.
Systems not able to integrate together.	Unable to disseminate data.

The challenge in implementing the scheme is therefore, not just that involved with the system design, which while satisfying the users present needs, must ensure that future enhancements can be introduced in an evolutionary manner, but that of ensuring that the systems installed truly meet the users requirements, that all associated with the use of the facilities and operational information provided by the system are adequately trained in its use and that effective support and maintenance is provided.

This paper therefore reviews not only the system design selected for NWWA's Regional Telemetry Scheme but more importantly the approach taken to define and validate the system user requirements at each stage of the scheme's lifecycle, the requirements for training and the approach to the overall mangement and quality assurance of the scheme.

THE MANAGEMENT CHALLENGE

Scheme Management Methodology

Faced with the need to install telemetry systems for the whole region as one integrated scheme, in a short a period as possible, and recognising some of the problems experienced with smaller schemes in the past, NWWA acknowledged the need for an organised, professional approach to the scheme management. A critical review of the project management requirements was carried out and a structured approach to the overall project lifecycle was adopted from the definition and requirements analysis phase to the maintenance phase.

In defining the approach to the scheme management,.of paramount importance was the requirement to formulate a system whereby user requirements could be effectively established and check points provided at various stages in the project in order to validate the system design against these requirements. One of the main conclusions of the Report on Instrumentation, Control and Automation in the Water Industry (National Steering Group of the Water Council, 1985) was to stress the importance of user considerations.

NWWA is divided into operating districts, each of which form an autonomous operational unit for either a single function; water supply, water distribution or water reclamation or for multiple operational functions. Each district is responsible for day-to-day operation of the facilities within its area with longer term planning and setting of standards being performed at Regional Headquarters. The day-to-day operation of each district varies, some being managed from a single central location whilst others are sub-divided into groups and sub-groups. Each district is responsible for a range of operational sites, the majority being unmanned and dependent upon routine visits to check on plant operational status whilst others may be manned either on an 8 hour shift basis and others on a 24 hours basis. In determining the initial system requirements it was recognised that a district is the focus for the normal reporting of day-to-day operational data. This formed the basis for the definition of the system design and indeed the strategy for the whole scheme. It was evident that the scope of the scheme, the monitoring of approximately 1200 sites to be implemented over a four-year period would necessitate a streamlined "production-line" approach to implementation with a high degree of standardisation, not only in the systems and equipment to be installed but also in the engineering and management of the scheme.

The implementation stage was therefore sub-divided into scheme level requirements and project level requirements. Each district was considered as a separate project, with data from its operational sites to be reported to the required operations centres within each area by the use of telemetry equipment, and the required measured parameters, status and alarm indications provided by the installation or refurbishment of the site instrumentation and equipment. In this way the total scheme was broken into a series of individual projects with each one essentially being independent of any others. The scheme level requirements were activities common to the scheme as a whole and applicable to all projects.

Three particular areas were highlighted as the key to successful completion of the scheme; the defintion of user requirements; training; and project management. In planning the scheme, user involvement was therefore considered at both the scheme and project level.

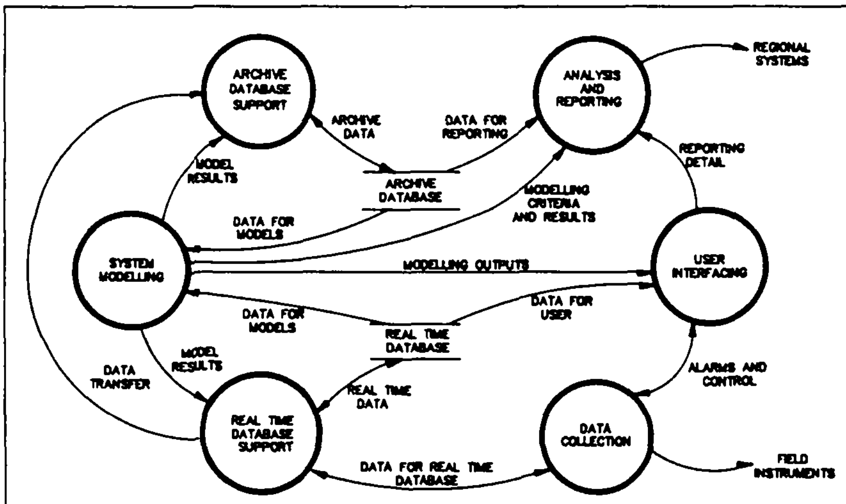

Figure 1 Main System Functions

Scheme Level User Requirements

User requirements were determined using a formal structured data analysis method which involved, an extensive series of discussions with users; a review and analysis of the manner in which the operational management of the Authority's plants is carried out on both a day-to-day and week-to-week basis and over longer periods of time; discussions with other Water Authorities who have installed and/or planning the installation of operational information networks; a review of the success and failures of other schemes within the Authority. Authority personnel considered in this review ranged from operations management to management information services staff. From this requirements study a data flow model of the system was established and the top level data flow diagram is shown in Figure 1. The formal definition of user requirements at a scheme level was fed back to users in the form of a scheme functional requirements document as a first formal milestone for user review.

The system design for the computer, telemetry and communications systems formed the next major activity at a scheme level followed by the definition of appropriate strategies for the placement of contracts for the various elements within the system.

Project Level User Requirements

In determining the initial strategy for introduction of the scheme a careful and thorough analysis was necessary to define the overall scope of the scheme. NWWA is responsible for over 6,000 individual operational sites and as the cost of providing monitoring of a site can be between £1,000 and £10,000 for the telemetry and instrumentation equipment, it is necessary that some criteria for the selection of operational priorities for the selection of sites and parameters for monitoring at each site was required. A major part of the feasibility stage was therefore to determine a criteria for site selection and an initial assessment of all sites against this criteria in order to establish the number and priorities for the sites which were to be monitored and the costs for implementing the scheme. This stage identified the need to provide monitoring of approximately 1200 sites for the intial phases of the scheme and a project implementation period of four years.

However, this evaluation, which was carried out at the feasibility stage, was primarily to establish the overall scope and budget for the scheme and did not attempt to define in details which particular sites were to be monitored. The initial planning for the scheme implementation divided the whole scheme into a number of individual projects. For each project it was therefore necessary to establish the detailed requirements including the selection of sites and parameters against the operational criteria developed during the feasability stage, and the location and number of operating centres for the telemetry system for each project. The definition of these requirements therefore became the next level of user requirements definition, termed the project user requirements.

The user requirements at the project level were established by the preparation of user specification for each project. User involvement was considered to be crucial to the success of the scheme, the District Manager for the area covered by each project was therefore given the responsibility for the preparation of the project user specification. The site selection criteria established at the feasibility stage was expanded into an operational criteria for site and measurement parameter selection and guidelines were prepared to assist users in the preparation of user specifications.

The user specifications were designed not only to cover the definition of which sites were to be monitored but also a number of basic parameters for the design of the associated telemetry system. The location and facilities required at each information reporting centre were defined in the user specification as were the presence of any existing telemetry or automation schemes which were required to be integrated into the system.

The project user specification was the first major milestone in the programme for each project and formed a benchmark for the users to refer back to in later stages in the project. The user specification also formed the basis for the design of the telemetry system for each project and for the instrumentation requirements at each site to make the various operational measurements available.

Scheme Level Design Requirements

The computer, telemetry and communication systems although forming the major technical challenge for the scheme only form approximately 35% of the total scheme cost. The other significant items are the engineering costs (25% of the total scheme costs) and the instrumentation supply and installation aspects (the remaining 40% of the total scheme costs).

Following the definition of the scheme level user requirements, a system specification was prepared which formed the basis of a request for quotations for the computer and telemetry systems. Following the requirement for standardisation and a "production-line" approach to the scheme, each district was allocated a standard telemetry master station which was designed around the same standard equipment, but more importantly providing the same software facilities. A modular range of outstations were specified allowing the correct configuration to be selected appropriate to each site. The contracts placed for the telemetry master stations and outstations were organised around a basic schedule of rates for the various items of equipment involved, such that the items priced in the contract could be used to build up an order for a particular system, once the detailed requirements were established. Thus the preparation of user specifications, establishing the detailed requirements for the telemetry system for each project, could proceed in parallel with the design and specification of the telemetry systems. The other major area of work was the requirements for instrumentation refurbishment and new provision at each site included in the scheme.

In order to apply the design and equipment standardisation required, a standardisation on instrumentation equipment and associated documentation was established. Bulk purchase contracts for the supply of instrumentation were organised, whereby prices for all instrumentation items were negotiated on a bulk supply basis following competitive tendering against instrument specifications. Guideline documents, drawings and standards were produced and used for the whole scheme for the selection, application and installation of instruments for the various measurements required.

Site Audit

Having established the requirements for each project, the next stage was to determine the detailed design requirements for the telemetry systems and instrumentation to enable orders for the telemetry equipment to be placed and specifications for the supply and installation of instrumentation equipment to be prepared. This was established by carrying out a site audit. The assessemnt of site refurbishment work involved determining what new instrumentation equipment was required, and also whether any existing instrumentation or telemetry equipment could be utilised.

The total scheme involves over 1200 sites in the initial phases, with the number of new instruments to be installed approaching 15,000 separate items. Each site had to be thoroughly audited with regard to location, identification, existing site services, existing instrumentation and telemetry and existing motor starters and drives to be monitored or controlled. It was clearly of great importance than a methodical approach to the collection of this data should be adopted. If data was collected in a haphazard way and extensive revisits to the sites become necessary because of missing information, then the timescales and costs for implementation of the scheme would be jeopardised. The large amount of data collected and the analysis and use of this data for various design and costing exercises meant that the audit data was amendable to computer processing.

A disciplined approach to the collection of data during the audit would have been of little significance if no clear requirement had been defined on which sites were to be audited and which measurement and control facilities were required at these sites. The project user specifications provided this data and formed the starting point for the audit. An important aspect of the audit was the definition on a site-by-site and loop-by-loop basis of the detailed extent of work necessary to make the required measured parameters available to the telemetry outstation. The cost of carrying out this work was estimated by using a cost database established in the computer.

Project Functional Specification

Having established the scope of signals required at each site within each project, the input/output schedule for each telemetry outstation could be determined. In addition the design of the telemetry system for each project was also defined at this stage, by consideration of the project user requirements and selection of the appropriate elements of the telemetry system established as part of the telemetry contract.

The project telemetry design, the site audit report and site instrumentation supply and installation scope of work reports, and the project costs were combined together to form a project functional specification. The functional specification was effectively a system design proposal for each project in response to the project user specifications. The functional specification therefore formed the next major milestone in the programme for each project and was also a checkpoint for discussion and agreement with the users. The functional specification was reviewed against the user specification requirements by the appropriate users and also checked against the budget allocated to the project. The telemetry design was reviewed with the telemetry contractors to ensure that a valid design had been proposed within the performance constraints specified.

Project Sanction and Management

Following operational and budget approval, orders for the telemetry system were placed against the purchasing contract for the telemetry systems and specifications prepared for the supply and installation of the instrumentation necessary for the project. Following assessment of the tenders for the instrument supply and installation, contracts were placed for each project.

Once the contracts for the site instrumentation and installation and the orders for the telemetry system for each project were placed, each project progressed to completion in a period of 12-15 months, with the usual activities of design review and approval, exchange of detailed design information with the various contractors involved, and installation and commissioning. During this period various reviews of progress and design proposals were fed back to the users, major checkpoints being the discussion and agreement of the graphical presentation and report generation of data on the telemetry system VDU's and the organisation of the site work.

Quality Assurance

The importance of quality assurance to the successful achievement of the scheme objectives was recognised at an early stage. The quality assurance requirements for all aspects of the work were based on BS5750. (British Standards Institute, 1979). These requirements were applied not only to the design and manufacture of all hardware and software, instrumentation and installatiion work but also for all design and project management activities. At the outset of the scheme a quality assurance plan was established setting down the overall requirements for the definition and management of all quality assurance activities for the scheme.

The ability of potential suppliers and contractors to work to BS5750 was evaluated by carrying out an audit of their quality assurance procedures prior to inclusion on tender lists for the various contracts. Subsequent monitoring of compliance to the scheme quality assurance requirements was made by periodic QA audits.

TABLE 2 - Training Programme

Scheme Activity	Training Module	Staff	Training Provided	Training Course
User specification Site audit Functional specification Planning and approval	A	Senior Managers	Introduction to scheme and training system	Presentation to managers. Familiarisation on training kit
	B	District Managers	Introduction to district project, user specifications and training system	1 day - "off the job", familiarisation with training kit
	C	Group Managers	Identify effects of functional requirements of standard system	Feedback into system design during functional specification/approval stage
Design	D	Systems Engineers	Introduction of standard system	5 day overview course at suppliers.
	E	Supervisors	Review of current operating procedures, work rotas, preparation of new operating procedure instructions	3 day overview course followed by 2 day system appreciation course
	F	Supervisors/shift Controller/ Control Room staff	Introduction to scheme, training system, new operating instructions, procedures and different sites	3 day session, followed by 1 day session with further joint development upto installation
Manufacture and Installation	G	System Operators/ Supervisors/Shift Controllers/ Control Room Staff	"Hands-on" training with training system	2 day visit to suppliers factory followed by "hands-on" experience
	H	Level 4 managers/ supervisors	Detailed familiarisation of own system, visit to suppliers factory during works testing	1 day visit to suppliers factory during factory testing
Commissioning	I	All system operators and craftsmen	"Hands-on" training own system	2 day "on-job" course, 2 week experience supported by local expert
	J	Operatives	Introduction of new procedure, instruction priority actions, VDU familiarisation, read only, alarm acceptance	½ day "off-job" course ½ day practical experience
Operating	K	Operatives	Develop knowledge of system capabilities and use of information	Regular discussion and review
	L	Operatives	Knowledge of different plants and treatment processes based on new procedures and operating instructions	On-off job course based on new procedures and operating instructions

Training

For any system to be effective in its operation it requires that users , firstly must be conversant with the facilities and opportunities it offers, and secondly must be confident in their use and operation of the system.

To meet these requirements it is essential that users be involved with the system from its planning through to the completion. This involvement must be active and must be accompanied by a structured, planned training programme. At the outset of the scheme such a training programme was designed and initiated. The programme was designed to ensure that when the telemetry systems are completed and handed over to become operational that those who will rely on these systems will readily claim ownership of them. This requires the gradual introduction of new concepts, operating procedures etc.

The training plan for the scheme and indeed any other system required that the following areas be addressed; operation of the system; maintenance of the system; managing the plant or process with the aid of the new system; developing and upgrading of the system.

The first two areas can be contractual on the suppliers of the system, providing that the purchaser's requirements are clearly stated in terms of course content, number of attendees, duration etc. and that the "quality" of the trainers has been approved.

The third area, that of managing the plant or process can only be undertaken by those having a close working knowledge of the current operating regime, the facilities available from the new system, and the intended or possible future operating regime. The current operating regime must be identified in the User Specification at the very start of the project, while the facilities available from the new system, and therefore a definition of new operating regimes, can only be determined by those closely involved in the design of the system. It is necessary therefore for both designers and users to work together in determining and providing this area of training. Training for the development and upgrading of the system requires particular and specific skills which are often embodied in a person having a detailed knowledge of both the plant or process and the telemetry system. This type of person is relatively new in the UK Water Industry and fulfils the role of "Systems Engineer" in its widest context. The development and training of such people is a long term task and is currently the subject of much discussion. Such a person is essential if the Water Industry is to maximise on the opportunities offered by such a complex system as the Regional Telemetry Scheme as a tool for the management of the water supply, distribution and reclamation cycle.

To ensure that training is carried out at the correct pace and time during the life cycle of the project, a training plan linked to key project events was established, This plan is shown in Table 2.

THE TECHNICAL CHALLENGE

Introduction

The design of any computer system application, whether it is for a single works or a large integrated scheme, is the basis for its implementation and while a good design does not ensure a successful outcome, a poor design will harm the project however well it is implemented. For a large scale telemet[illegible] scheme, there are many objectives to be satisfied, some of which may not be directly associated with the [illegible] si[illegible] [illegible]ole of the scheme, while others cannot be precisely defined. In this context it is not surprising [illegible] in [illegible] hat telemetry schemes have often gained a bad reputation where the design has failed to meet th[illegible] re[illegible] and perhaps unstated objectives, and where the scheme is unable to be used to its full effect.

The increasing scale of telemetry schemes, moving from single master station schemes with perhaps 25 sites for local supervision, to schemes including upto 2000 sites with a much broader range of functions, means that system design, which was always important, now has a crucial importance to ensure the success of the large investments made in these schemes.

A scheme of the scale of the NWWA Regional Telemetry Scheme has roles to play in many aspects of operational management, ranging from the reporting of abnormal conditions to a district supervisor, to the longer term monitoring and scheduling of resources and to the identification of capacity limitations which form a key input to strategic investment decisions. The scheme includes large treatment works, long distance transport networks and numerous smaller installations, each of which must be monitored at an appropriate and cost effective level. Also included are groups of sites associated with higher level functions, such as river flow modelling and forecasting or for the modelling of distribution networks and optimisation of plant. These must all work together in an integrated manner.

A less tangible, but none the less important, implication of the scheme is the diversity of function and structure of the different parts of the organisation which it is intended to serve. A scheme of this scale can only be fully effective if it is able to provide for the different perspectives of all its users. However, a clear view of the basic reason for its installation, that is to improve operational effectiveness, must be retained or the scheme can be dissipated in providing numerous secondary functions. The dimensions of a large telemetry scheme means that the choice of design and method of implementation must be made on a sound basis of understanding of the requirements, a strong technical appreciation of the possibilities and a sensitive judgement based upon experience of schemes of a similar scale. This section reviews some of the considerations in selecting a suitable system design and in establishing the system requirements.

Requirements of System Design

General. The requirements for the design of the scheme fall into four categories.

Operational requirements which reflect the needs of the user in the primary function of control and supervision of the operational sites.

Management requirements which are concerned with ensuring the effective use of the system for operational management, both for short term and longer term activities.

The system requirements which indentify those technical facets of the design which affect the usefulness of the system in the short term and in changing future conditions.

Finally, and of great importance to successful implementation of the scheme, are the commercial requirements.

Operational requirements. The scheme must meet the needs of the users in terms of the facilities for supervision, data collection and remote control of sites. Different facilities are required according to the size and function of individual sites and for different operational districts. Supervisory control of sites may be required to be performed by the telemetry scheme with provision for example for loading pump duty schedules remotely into outstations to permit optimisation of energy use.

The scheme was also required to provide a capability to incorporate modelling and analytical facilities to support operational activities. These facilities were not required to be provided at the outset, but will be incorporated during later phases of the scheme as will network modelling for the generation of optimised pumping schedules.

Finally, the telemetry system must provide a simple operator interface at each level, so that operatonal staff have free access to the information they require, without the structure of the telemetry system itself imposing limitations on their ability to obtain a clear view of the current situation. This requirement has a significant impact on the design of both the operator facilities and the communications network which serves the operational centres.

Management requirements. Experience has shown that the introduction of an effective and comprehensive telemetry system has a major impact of site supervision, operation and management.

The way in which a particular operational district responds to the opportunities for more effective use of operational resources permitted by telemetry, will depend largely on local circumstances. Consequently, it will be difficult to predict during the design stage possible changes in operational staff organisation. The telemetry system must, therefore, be flexible to allow for subsequent changes in the operational management structure.

The telemetry system will provide more information for operational management to optimise and economise the provision of services. To make use of this information the system must be able to pass data to other systems to assist with short term optimisation and to management systems to allow effective use of the current and historical data.

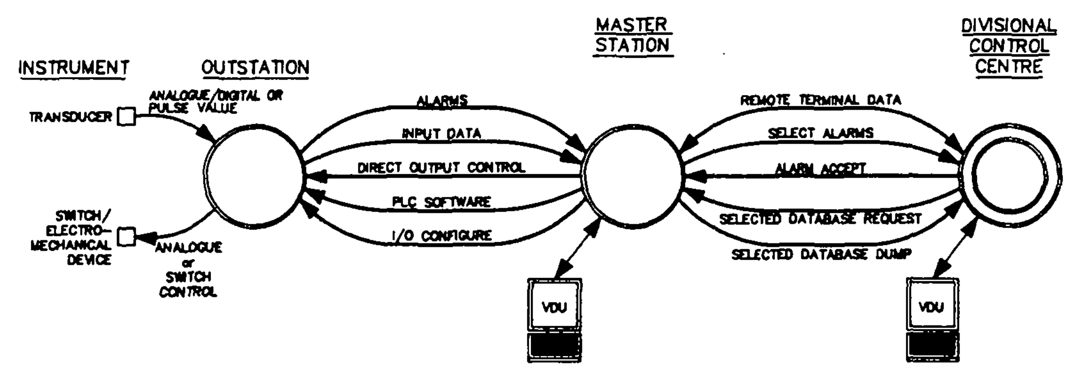

Figure 2 Telemetry System Design

System requirements. The system design must incorporate features to ensure that the system is reliable and that in event of failure its major functions are not disrupted. Target levels of availability for different parts of the system must be defined so that the system structure, communications network and equipment design can be selected to maintain these levels of service despite internal and external failure.

The need for flexibility in the system design to satisfy changing operational and management requirements has already been identified. The system must be capable of expansion to include more sites and to allow development to provide additional functions and facilities within the existing framework. Such enhancements include the integration of the existing weather radar data and its dissemination throughtout the system for the optimisation of performance. The design was also required to provide the desired flexibility without unreasonable additional cost at the outset but also provide ready means for subsequent economic development.

Commercial requirements. A major commercial factor is the requirement for the minimum cost of ownership. This requires that the design balance both initial capital cost with annual revenue costs, such as communication, spares and support costs, to give a minimum cost over the life of the system.

In view of the scale of the system and the need to proceed as resources become available, it was necessary to arrange for phasing of the work over a number of years. This necessitated the selection of design and contractual means to control costs for subsequent phases of work.

The design also had to provide for successful integration of those existing systems which could be economically included. Furthermore, the design should, as far as possible, permit alternative supplier's equipment to be incorporated at a later date if this offers a more cost effective solution to changing requirements.

Finally, in view of the pressure of competing orders placed with the major UK telemetry suppliers, the design had to provide suitable means of control of suppliers. The impact of this requirement on the design was mainly in terms of providing a modular approach with standard interfaces permitting the use of two telemetry suppliers to offer both commercial and technical flexibility for the scheme implementation.

Scheme design

The telemetry scheme includes functions at a number of levels as shown in Figure 2.

At the site level the plant interface includes sensors, instrumentation and interfaces to existing equipment. The links to existing equipment and provision and installation of new equipment on site represent the largest category of expenditure in the scheme.

Also at the site level but acting as a link to higher level functions are the outstations. The correct definition of outstation facilities, their scale and scope for expansion was very important to the longer term development of the scheme as well as to its immediate cost.

Supervision for group of sites is based around the district master station, which typically are manned during normal working hours only, and depots or other locations which require occasional information or act as the prime reporting locations for a sub-group of sites within a district. Above this level there are three Area centres which will be manned and have special arrangements to provide supervision on a 24 hour basis.

The Area 24 hour operating centres provide for some management information and analysis but there are links for higher level facilities to be provided by management information systems. An important aspect of the design was to select the most effective balance of functions between the telemetry systems and the Authority's business computing systems.

A wide range of system configurations may be adopted for a large telemetry scheme. As discussed previously, establishing the user requirements for the scheme was the starting point for the system design with the preparation of a functional specification being an intermediate point necessary to define the system requirements. A formal structured approach to definition of the system functional requirements was carried out and functional decomposition from the top level data flow diagram as shown in Figure 1 provided a detailed set of data flow diagrams describing the system functional requirements. From this analysis a separation of the various functions and facilities of the system into a system hardware implementation could be considered.

Figure 3 shows the overall system design which was selected. As the operational district form the basis of the day-to-day operation and management it was decided to provide a telemetry master station for each district. A total of 36 telemetry master stations therefore formed the basic telemetry network for the scheme. At the site level outstations were installed and connected to their appropriate master station via communication links to allow remote control and supervision. At the master station level, systems were paired such that in the event of failure of one master station, its adjacent paired system could provide back-up and take over the functions of collecting information from the outstations of the failed master station. This approach met the user requirement for 99.5% system availability. In addition to the links between paired master stations for back-up purposes, communication links between groups of operationally related master stations were provided such that any master station in a networked group can interchange information with any other master station. Operator display and reporting facilities and operator man machine interface facilities were provided by VDU's, logging and alarm printers and graphics printers and XY plotters with each master station. Multiple operator work stations were installed where necessary to provide multiple reporting centres, either locally to the master station location or remotely over the Authority's Regional Communications Network.

A system of alarm priorities was established whereby alarms could be automatically switched to a manned centre no matter what time of day. Ultimately, on an out of hours basis, alarms were routed to the appropriate 24 hour centre. Where operators at the 24 hour centres require supporting information relating to response to alarm calls or where co-ordination of emergency situation across a wide area is required, the 24 hour system can access all data stored at the master station level. In addition, data for archive purposes, resource planning functions and other management information tasks is also passed from the master stations to the network of Area, 24 hour systems. The 24 hour centre network of systems was provided by a networked connection of four computer systems, one for each Area and a fourth for system programme development and support and to act as a regional emergency co-ordination centre.

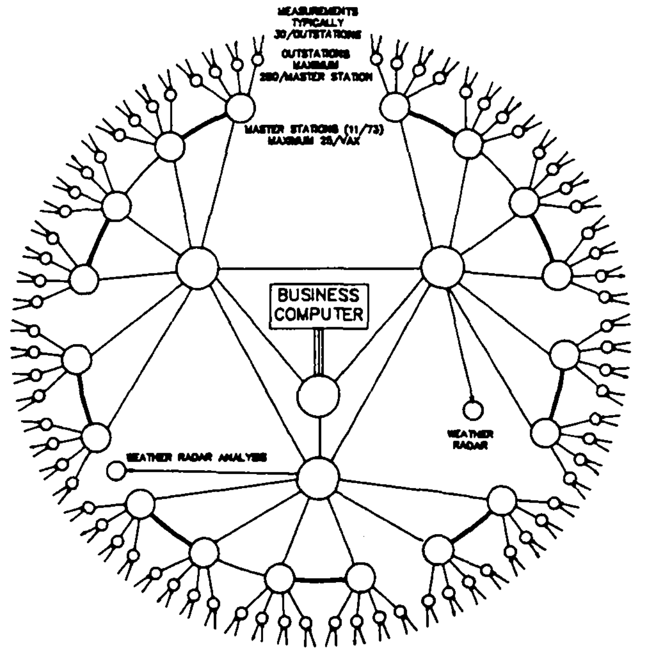

Figure 3 Overall System Configuration

<u>Communications</u>

As with any complex data network, communications play a key role. The five groups of equipment outlined, i.e. field devices, outstations, district reporting centres, 24 hour area centres and the management computer systems all require a detailed analysis of their communication requirements. This analysis must take account of operational needs e.g. frequency of report, cost, system responses etc and system needs e.g. electrical convectivity, speed of data transmission, data corruption etc. Along with these requirements must go consideration of security, reliability resilience, etc in a large range of operating situations.

The approach taken by NWWA is to utilise the intelligence of the outstations to enable transmission to and from the plant to be minimised. This allows the use of low cost PSTN. Where this is insufficient, usually for reasons of security, private wire, leased line or radio is used.

Figure 4 illustrates the higher level communications network which is being developed and installed alongside the Regional Telemetry Scheme. Use is made of several different carriers e.g. 140Mbit/s links supplied by Mercury, 2Mbit/s link from British Telecom and NWWA's private 1.3GHz radio network. The major communication nodes are lined by dual routes and alternative carriers so providing a high degree of resilience and redundancy.

FUTURE DEVELOPMENTS

Major operational information systems particularly of the nature of NWWA's Regional Telemetry Scheme would be incomplete without the ability to incorporate future developments.

Figure 5 illustrates where the telemetry systems fit into the overall water cycle control and management model. Considerable time was spent in identifying the data flow requirements to and from the telemetry system; this is essential to ensure that sufficient links are provided in the telemetry software to facilitate a smooth upward and outward development path.

Although telemetry is shown at the lowest level of the model, it is the most fundamental as all other decisions, predictions and algorithms depend on the data collected by the telemetry system.

As further layers in the model are implemented, then the telemetry systems will be enhanced to accommodate telecontrol, modelling, optimisation, predictions etc. The following applications are illustrative of the planned future development (over the next 4-5 years) of the telemetry systems now being installed.

Modelling and Optimisation

The energy costs for NWWA is in excess of £17M per annum. It is essential that by using modelling and optimisation techniques that costs can be reduced by at least 6% giving a revenue saving per annum of over £1M.

Modelling techniques are being used to firstly provide a better understanding of the supply/distribution network and then to provide dynamic information of the situation at points in the network which are not monitored directly. Modelling also enables flowmeters and pressure transducers to be positioned correctly in the network. Further uses of modelling are in the prediction of rainfall effects on river and lake levels and flows and hence assist in flood warning. North West Water has been at the forefront in the development of weather radar systems to input data to such models.

Optimisation techniques are used to ensure that pumps, treatment processes, etc., are operating at the optimum performance. The criteria for optimisation are obviously different for each item of plant and for each system subsystem but generally systems are optimised to ensure that customers requirements are met with the minimum costs.

Management Information Systems (MIS)

MIS is widely used in the water industry and currently includes data such as man-hours, performance aims and other manually-entered parameters such as power consumed, water consumed, etc. With the advent of integrated telemetry schemes, operational data can be automatically inputted to MIS allowing management to have on-line access to processed data such as water stock and demand, efficiency of plant, consumer demand, maintenance requirements, etc.

Digital Mapping

Many of the assets of the water industry are buried underground, i.e. pipes, sewers, etc. The precise position of these is currently held on paper records. The industry is now starting to transfer these records to digitised maps. Such techniques enable detailed records to be held of pipe size, type, age, etc. This information can be transmitted to mobile staff via the communications network, who are tasked with repairing leaks, burst, etc. Telemetered data will be used as an overlay to digitised maps to provide a complete picture of the status of the network.

IKBS (Intelligent Knowledge Based Systems)

IKBS is now starting to be developed to assist operations management in decision making. One such application is in alarm management. The basis justification for any telemetry scheme within the water industry is to inform of any exceptional events, i.e. events which indicate operational failure or operations outside predetermined norms. The required reaction to these exceptional events needs to take account of many factors such as network knowledge, environmental knowledge e.g. rainfall, customer complaints and telemetered data. IKBS will be used to advise the operator on what action to take having considered those inputs and their current state.

CONCLUSIONS

NWWA embarked in early 1985 on an ambitious programme to provide an infrastructure of telemetry based control and monitoring schemes thoughout the region as the first element in an operational mangement and decision support system. The scheme is seen as crucial to the effective and efficient management of the Authority's resources for the next decade and beyond.

Although the system design selected will be a critical factor in ensuring the success of the scheme, the major challenge presented by the scheme is not that of the technology involved but that of making the technology work effectively. Too often in the past insufficient attention has been paid to; the definition and validation of user requirements; to training requirements and to the process of project management.

The Authority recognised the important of these factors and in order to ensure the successful implementation of the scheme, considerable emphasis has been placed on the planning of the scheme, of user involvement, of definition of user requirements and training of all potential users of the system and of the information provided by the scheme.

The installation of such systems is seen as one of the key technologies which assist the Industry in meeting the inevitable challenges faced not only today but for the next decade towards the year 2000.

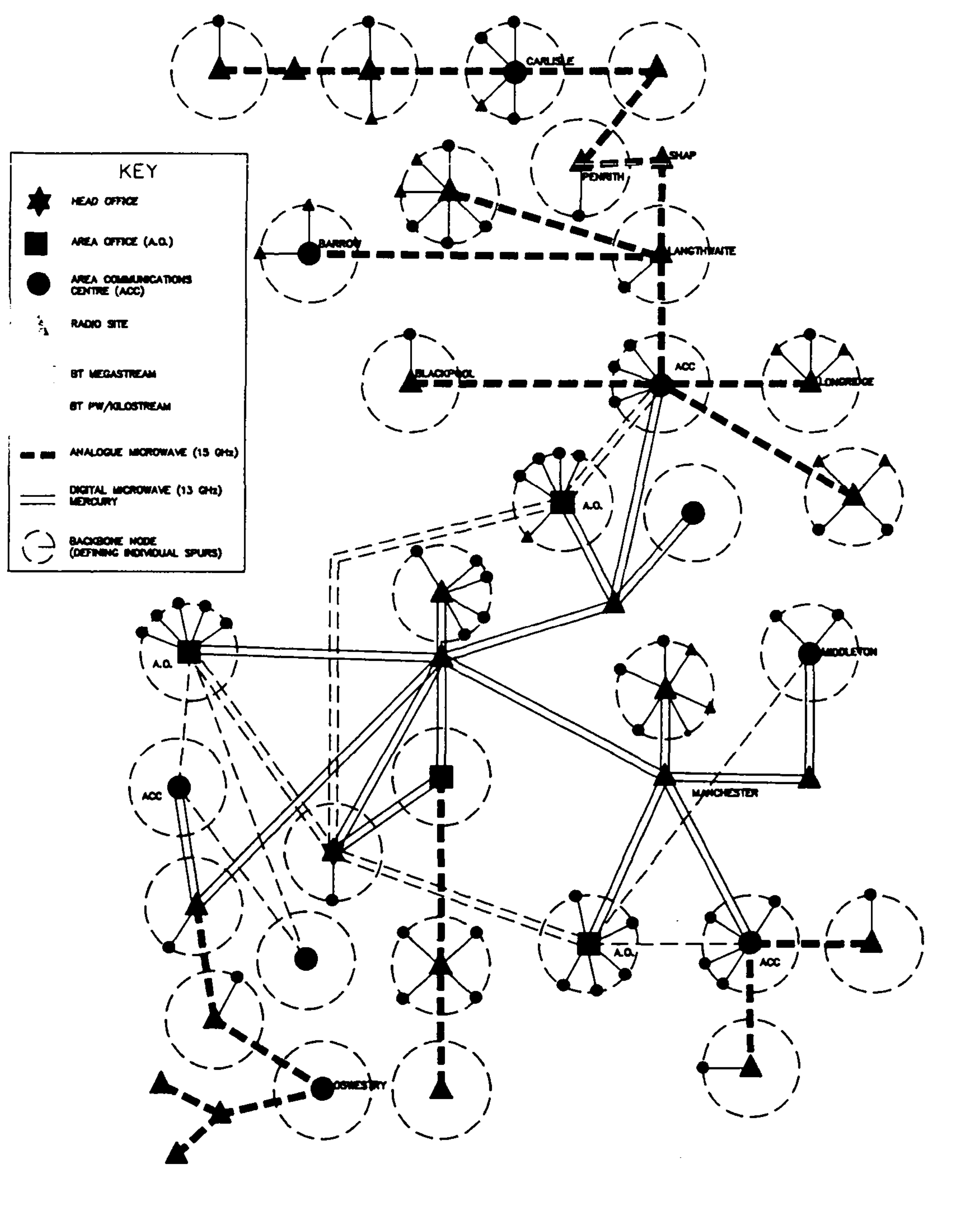

Figure 4 Regional Communications Network

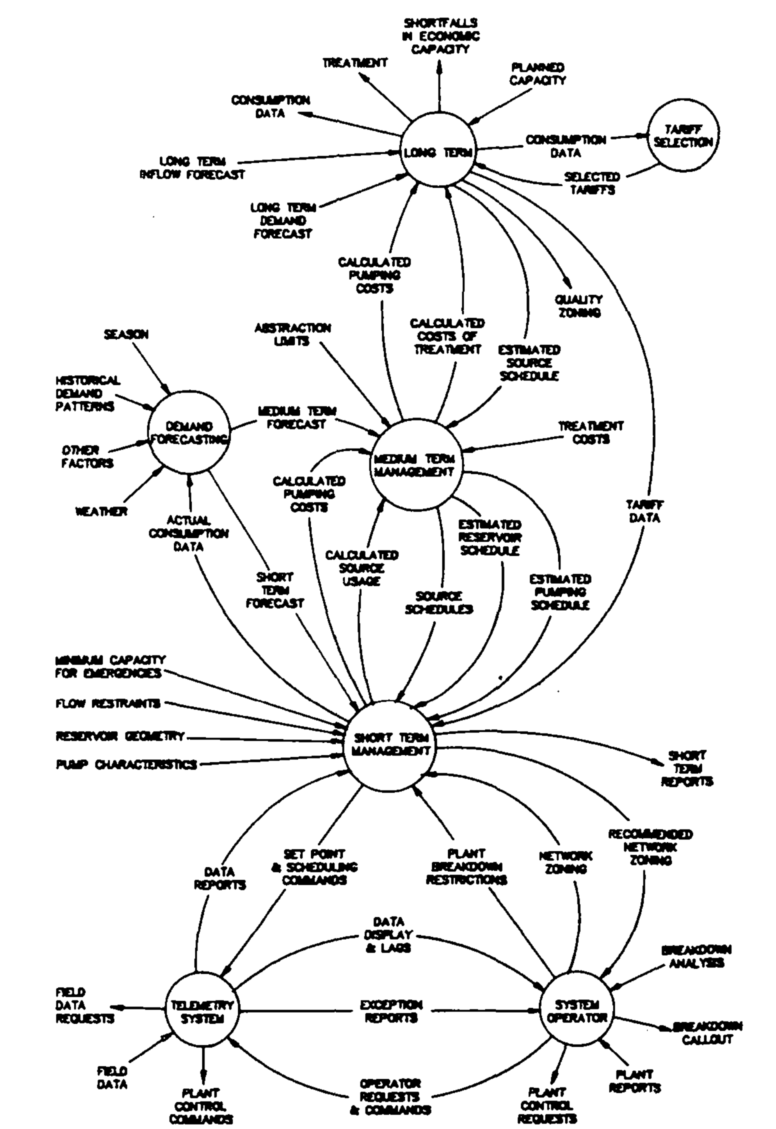

Figure 5 Water System Optimisation & Management

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SAFE DRINKING WATER SUPPLY BY AUTOMATION AT THE EXAMPLE OF THE CITY OF HAMBURG

Dr.-Ing. H. Al Hames, Hamburg
Director of the Department Water Supply
Hamburger Wasserwerke GmbH
Federal Republic of Germany

INTRODUCTION

The Hamburg Waterworks supply in the area of the Free and Hanseatic City of Hamburg and 27 surrounding communities approximately 2 million inhabitants with drinking water. The distributed drinking water is abstracted by 500 wells from groundwater and treated in 21 waterworks. In the average some 450,000 m^3/d and during peak flow up to 700,000 m^3/d are consumed.

With a networks pipe length of 5,300 km the Hamburg distribution net is the largest in the Federal Republic of Germany. By suitable arrangements of the transportation mains, which partly combine different waterworks directly, it is possible to transfer larger amounts of needed water from one part of the network to another. Thus during peak flow sufficient amounts of water may be shifted from the abstraction areas to the main points of consumption, avoiding shortages and warranting a higher safety in supply. The hydraulic conditions are favoured by the support of reservoirs at the feeding waterworks. In total the Hamburg Waterworks possess a reservoir volume of some 350,000 m^3.

The areas in Northern Germany have normally favourable conditions for natural ground water replenishment and ground water use. Even if drinking water supply from ground water is essentially safer there are latent dangers from anthropogenic and geogenic effects. On the base of the explained complexes the hydraulic, hydrological, and technical restrictions have to be considered as function of site and time. Supervision and control have been fulfilled until now by local works personnel and automatic facilities.

The establishment of a central supervision and optimation project will allow to achieve the following goals:

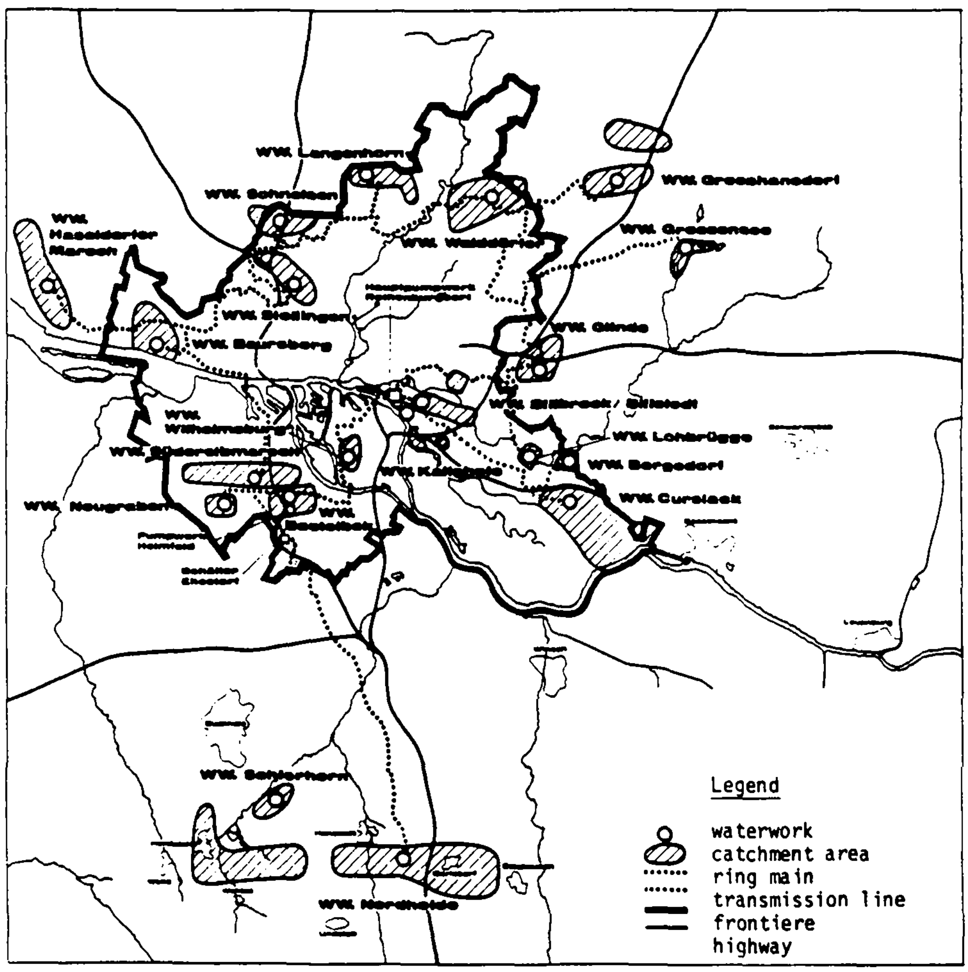

Fig. 1 Supply System of the Hamburg Waterworks

STRATEGIC MEASURES

This situation needs a problem orientated supply strategy until further than year 2000. The analyse of consumption and yield for the longterm safeguard of the drinking water supply needs on one hand protection of ressources against geogenic and anthroprogenic effects with the main goal to reserve and safeguard the undangered ground water for drinking water supply. On the other hand there is the strategy of saving water meaning the influence on people to use drinkwater as rational as possible. The strategy on protection of the ressources comprises the following elements:

- establishment of drinking water protection areas
- management of ground water source problem oriented
- intensify water quality control and quality safeguard
- minimize or block off sources of decontamination
- further development and rationalization of supply systems.

Within the operational measures on realisation of the fixed strategies and considering the complicated present and future drinking water supply situation the Hamburg Waterworks have started the research project on "demonstration of the optimum interconnected system of the drinking water supply in Hamburg".

The realisation of a central control and optimization project allows to approach the following goals:

- reduction in investment cost
- reduction of operating and repair cost
- improvement of personnel supply
- improvement of communication
- increase of supply safety
- improvement of product quality and reduction of environmental influences

The first design of the system intended a central twin computer system with remote control lines to different waterworks. Essentially this conception comprised the central data collection and processing of all operation and disturbance datas as well as the central forecast in models of fixed nominal values to the conventional control automates within the waterworks.

Decisive weak points of this centralistic conception were:

- endangering of the safeguard by too many remote control connections
- achieving tolerable reaction times of a realtime.operation
- lack of intelligent redundance in the waterworks.

Concerning these deficiency the new conception has been developed and a strictly hierachically system subdiveded in autonomical subsystem has been chosen in order to guarantee clearness, flexibility and safety for execution of the different tasks even in cases of alteration and additions in the supply structures.

TECHNICAL CONSEPTION

Level "1" - Background computer

With the aid of the background computer the calculation intensive models, forecast, cost, and net optimization models, receiving and giving in fluctuation actual information from the following level, will normally be handled.

Level "2" - Net computer

The net computer will handle the organisation of the data transmittance, the central data collection, the servicing of the central information system as well as the keeping of the archives for central tasks. It will execute the central total survey and control by nominal values for the different works.

Level "3" - Group control computer

The level of the group control computers consists of micro computers, being situated in the group control works. They will receive the leading data from the higher level and - if concerning the group control system - apply or transmit to the next level or vice-versa. The works installations and the following level will be operated and controlled directly from the micro computer.

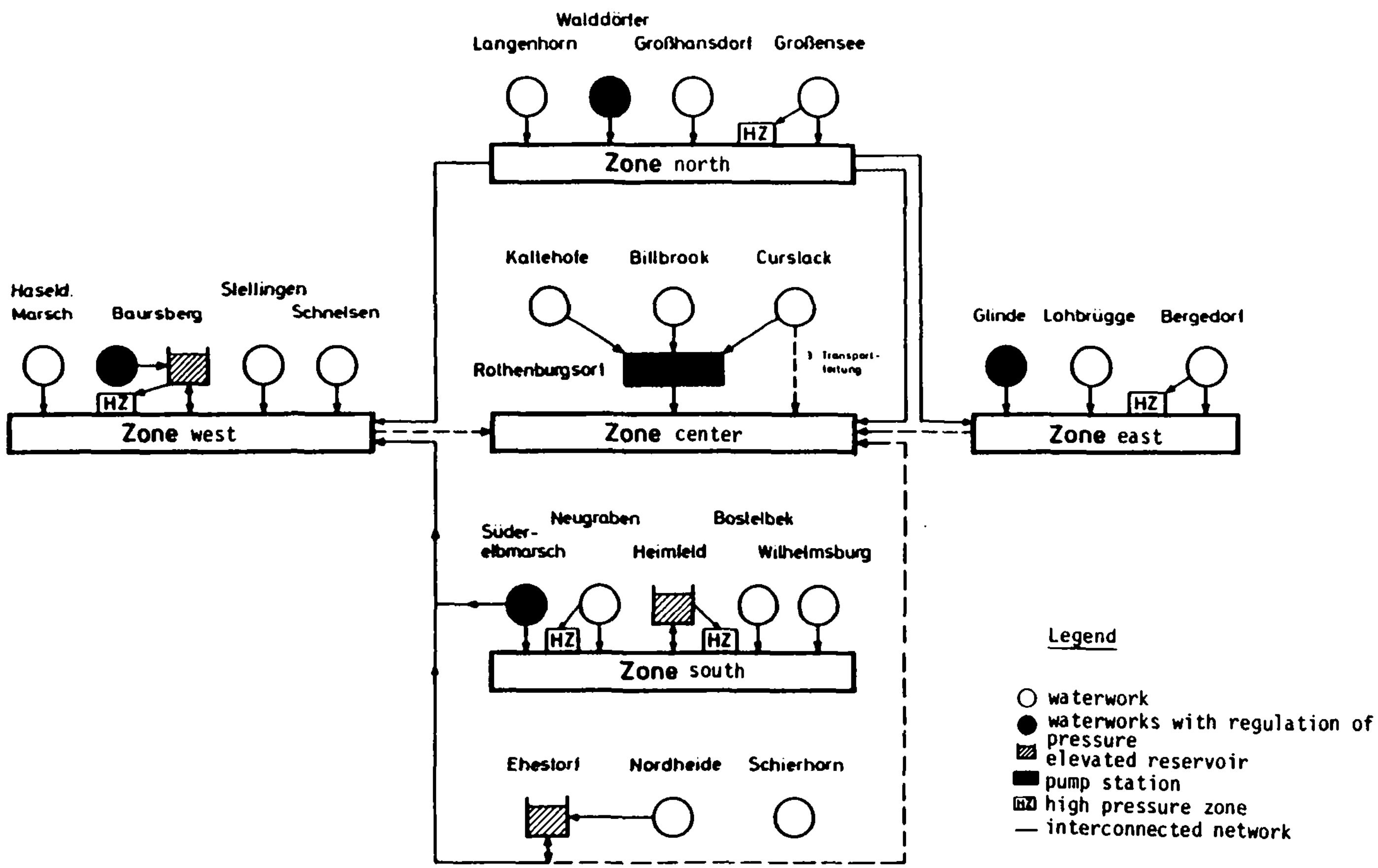

Fig. 2 Scheme of supply structure

Supervision and control system

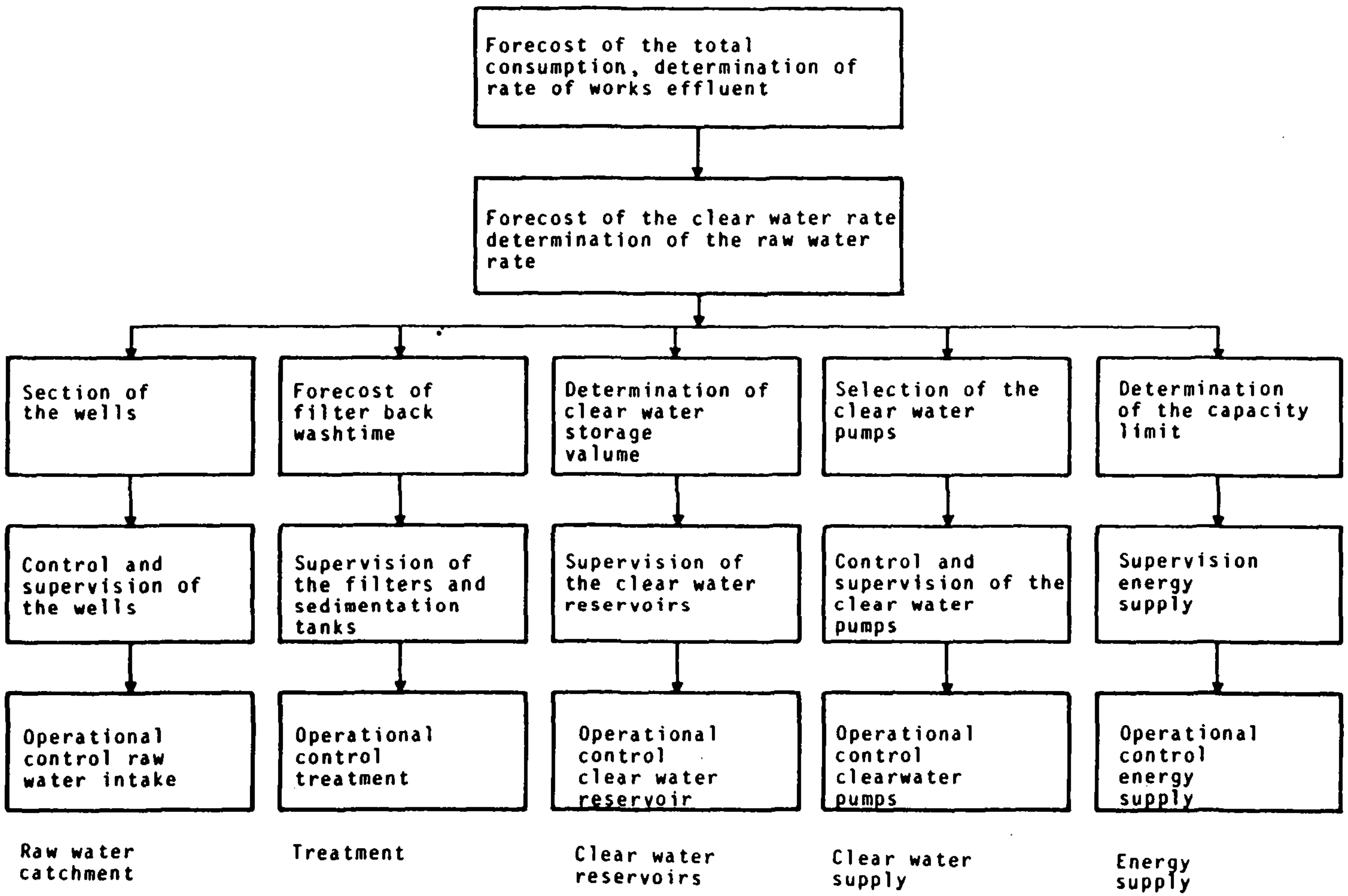

Fig. 3

Level "4" - Micro computer

This level is due to size and impotance of the waterwork equipped with a micro computer. Each of these devices is directly connected to the respective group computer. In the works, approaching in size and rate the group work micro computers are installed. The micro computers are so called DRT's (DEA) (data receiving and transmitting devices) forming also the process interface of all computers in the levels 2 and 3.

Level "5" - Subordinated computer

In some of the larger waterworks in which the data volume exceeds the system capacity of the micro computer, additional micro computers will advisable be installed to control certain aggregates. Instead of this level in future each aggregate will be equipped with micro computers replacing conventional techniques.

The application software comprises:

- communication system
- transmittance system
- supervision system
- control system

With forecast and optimization models the most favourable operation conditions will be determinded for the coming 24 hours in order to achieve optimum management of the water ressources with best possible water quality and lowest operational effort.

The determined hour-values are overtaken from the work systems as nominal values. The actual adaption to the needs is realized without timelag by warranting net pressure. Pump selection programmes in the work computers control the clear water pumps, while for automation of the raw water abstraction and the treatment seperate programmable controllers are applied. In the larger works there are additionally separate control systems for the net pumps to overtake without interruption in time the control of the drinking water supply.

From consumption in the zones the daily amounts of the works and the amount of water exchanged amongst the zones are determined.

They have to be evaluated such that the energy cost for abstraction, treatment, pumping and distribution will be minimized.

- The daily consumption in a zone will be balanced by the works and the reservoirs of the respective zone.
- The daily amounted clear water deliverable from a work is limited to both sides by the maximum respectively minimum daily volume of inflowing raw water and the reservoir volume.
- The amount of clear water to be delivered daily from a work is also restricted to both sides by the clear water capacity.
- In order to minimize the energy cost for transport of water between the adjacent zones the hourly rates are lowered and distributed over as many hours as possible.
- The amount of water delivered by the other zones to a zone limited by the forecast rate, the minimum and maximum pumping rate of the works and the amount abstractable from or storable in the reservoirs.

ADDITIONAL QUANTITIVE AND QUALITY SUPERVISION STRATEGY

The demonstrated system of the central load distribution warrants a clear presentation and archiving of the operational conditions at a central point. All measuring points essential for the operational control are considered quantitatively. At the same time the system is understood as a tool for reaching the objective of an optimal and environmental water ressource policy for the different ground water ressources.

The increasing geogenic and anthropogenic effects on ground water call in cases of total valuation of the ressources for an uptake of quality parameters as part of the data - description of a measuring point. Only thus a directed interpretation with the aid of data processing may be able.

The Hamburger Waterworks have therefore started to build up a data bank for water management and laboratory. Only by this way quick reactions on cases of disturbance may be achieved and longterm trend calculations under consideration of an adequate number of past values may be possible.

The system consists in the first stage of a data bank computer with 2 respectively 5 multiterminal subcomputers for the department water management/ecology and central laboratory. In sight of the computer the tasks of this computer net are as follows:

As central system and data computer a Siemens system 7.530-D is applied. This computer stores all data of the system and delivers them to the different interpretation components. Furthermore the SESAM databank forms the intersecting point between all components of the system.

In the considered subsystems the following different working modi are provided:

a) Interpretation of centrally stored data by the departments - down load from data bank.

b) Uptake, plausibility check and pre-processing of data at the working place with upload in the central data bank (storage in the central data bank).

c) Self-sufficient working place for office automation and expert application (called off-line or stand-alone or local modus).

to a:)
The special departments need often changing interpretation of central datas and frequently changing interpretation goals. This wide spectrum of applications may neither be defined completely in advance nor economically developed by additional, individual programmes during operation. The logical consequence means to tap the central data bank by the personal computer and to overtake the wanted data with local data bank. After that it is easy to adjust interactively to the changing interpretation needs with available software tooles (tools, sesam-final/applicant/service).

to b):
The personal computer offers respective indication and realization masks with which the responsible department may check the data and free them for transaction into the central data bank.

to c):
Known applications in the local operation such as text processing, table calculation, administration of time calender, programme development and the like.

WATERSUPPLY SPECIFIC APPLICATIONS

Watermanagement/ecology

With the application of the effective data bank system the provision for quick and safe water engineering decisions is established. They may be derived from the following requirements:

- simplified and safeguarded collection, transmittance, and storage of datas including computer interpretation
- building up measuring data loggings from the existing measuring programme
- determination of the main values according to the water ressources policy rules
- quality supervision at the surface and groundwater, trend calculations, punctual distinguish of danger situation as well as the introduction of preventive measures
- calculation of water balances (effluent, infiltration, evaporation)
- presentation of drilling profiles and geological sections
- continuous care of main and measuring data logging, control and actualisation of the data as well as the drawings and map material
- graphical presentation of the measured and calculated data in the form of hydrographs, bloc diagrammes, isolines and the like.

CENTRAL LABORATORY

The computer subsystem of the central laboratory forms in connection with the data bank computer the lab management system with the following functions:

- Entry and transit control of the water samples and others and its management
- Manual and automatic lab and measuring data collection
- Release of the lab and measuring data
- Transfer of the datas for the central data bank computer
- Presentation of the datas in tables and in graphical form on the monitor, printer and plotter

Because of the chosen systemtopology and the softwarestructure it is warranted that the operation of the lab may be continued even in the case of temporary break down of the data bank computer. As mentioned already it is irrevocable that relevant datas of the system of the central load distribution have to integrated into the water management and laboratory data bank, e.g. these data elements (measuring datas) have to be considered in the design of the structure of the data bank.

As future integration conceptions the datas of the departments operation of waterworks and water distribution have to be considered in the computer aided decision finding for a safe supply under conditions of economical application of energetic, material and labour ressources as well as yield values.

RESULTS

The investment cost of the total optimizing conception amounted to 26,5 million DM. The distribution of cost to the different sections shows the following picture:

20 % to process linkage and apparative extensions
20 % to hard ware
20 % to soft ware and
40 % to cable net

The system is taken under operation for the different zones. The first experience datas for the safeguard in the water supply are positive. The chosen strategy with its different time related operations allow to optimize also in future supervision and control of operation processes based on an effective process computer system. By quicker and improved information on operation conditions to central points the relations between water intakes, water distribution and water consumption may be analysed, interpretated anf forecast for a quantity and quality related management.

The technical solution of such complexes leads to durable technical and economical safeguard of the water supply.

SESSION 10

SEANCE 10

Chairman
Président J. ROBINSON

- Strategies of Future Research for Preparation of Drinking Water

  Stratégies de recherches futures en préparation de l'eau potable

  H. Bernhardt

- Emerging Technologies in the Water Supply Industry

  Technologies émergeantes dans l'industrie de la distribution de l'eau

  J. F. Manwaring

- Potable Water Treatment Techniques toward the year 2000

  Techniques de traitement de l'eau potable vers l'an 2000

  J. Sibony

Discussion

STRATEGIES OF FUTURE RESEARCH IN THE PREPARATION OF DRINKING WATER

Professor Dr. H. Bernhardt,
Wahnbach Reservoir Association, Siegburg.

ABSTRACT

Increasing demands on drinking-water quality and a continual rise in the loading of waters with micro-pollutants as well as the recently gained knowledge of undesirable effects of traditional water treatment processes on the water purity require the development of new treatment techniques or modification of existing processes. The foregoing is illustrated with the example of the oxidation processes involving chlorine and chlorine dioxide. As a consequence basic and applied research is necessary, for example in biotechnology especially nitrification as well as to develop a new disinfection strategy to obviate the use of chemical disinfectants.

KEYWORDS

Drinking water quality; micropollution; water treatment; biotechnology; flocculation; filtration; disinfection; process control.

INTRODUCTION

The problems which arise during drinking-water production are associated with the difference between the quality of the raw water and the requirements of the drinking-water quality. In the past, the quality of raw water has been steadily deteriorating in spite of increased efforts in water pollution control. At the same time, the requirements for drinking-water quality have become continually more stringent.

WATER POLLUTION AND REQUIREMENTS FOR DRINKING-WATER QUALITY

Due to the increased loading of the aqueous environment with harmful inorganic and organic materials, their levels have now reached a point which allows them to be detected in a large number of rivers and lakes. Amongst the organic substances, toxicological importance is mainly given to the hydrophobic compounds even though as micro-pollutants they occur in concentrations of only a few µg/l and contribute to about 1% of the DOC (Kühn and Clifford, 1985). Our ignorance of the significance of the large remainder of the organic substances to human health also provides a considerable source of uncertainty for drinking-water supplies. Some indication of carcinogenicity and mutagenicity already exists (Frimmel, 1987).

The elucidation of the composition of these complex mixtures, particularly with regard to their behaviour during water treatment as well as investigations on their relevance to health when they remain in drinking-water require years of extensive research work (Sontheimer and coworkers, 1985; Gimbel and Maelzer, 1987; Sontheimer and Völker, 1987).

Intensive agricultural practice is also the cause of increasing pollution of surface and ground waters, particularly through the use of fertilizers (phosphates and nitrates) and pesticides. These substances have already led to the existing"nitrate and pesticide problem" for drinking-water supplies and are the cause of an unnatural eutrophication not only of lakes, but also of flowing waters, amongst which, impounded rivers are particularly affected.

The solution to the nitrate and pesticide problem which is a task assigned to the technology of water treatment is just as much an activity for the future as is the prevention of eutrophication of waters which are used as sources of drinking-water.

The perpetual contamination of ground water with low amounts of harmful organic and inorganic substances from refuse tips and open dumping areas, which are still being discovered throughout the whole country and which are the result of a completely inadequate water conservation policy over the last decades, sets new and in some cases as yet undefined tasks for workers in the field of drinking-water production.

On the whole, the conclusion can be drawn that within the last decade the micropullution of our water with inorganic and organic matter has increased very considerably.

At the same time, the requirements for the purity of drinking-water have become more exacting. This is the result of:

- the continual improvements in the efficiency of water analysis with which it is possible to detect a wider range of substances in ever decreasing concentrations and
- the increasing knowledge of the hygienic relevance of the substances and classes of substances which are now detectable in drinking-water and their importance to health.

As a consequence, new concentration limits are being laid down for an increasing number of substances and classes of substances and the limits aready determined for known compounds are being revised and lowered. In this connection, both on principle and to protect the water supply against possible but as yet unconfirmed health hazards for the consumer, precautionary measures are gaining in importance.

In this way, permissible concentration limits are being set or made more restrictive independent of the health relevance of the parameter in question.

This development is shown clearly with a comparison of the requirements for drinking-water of the WHO in 1970 and 1984 (TABLE 1); (WHO, 1970, 1984). Independent of this, the EC has laid down maximum admissible concentrations (MAC) e.g. for pesticides 0.1 µg/l for individual compounds and 0.5 µg/l for the sum parameter (EEC, 1980).

Tab. 1 Comparision of selected guide values for Drinking-water lade down by the WHO IN 1970 and 1984

Inorganic constituents of health significance (extract)

Constituent	Unit	Upper limit of concentration 1970 x)	Guideline value 1984 xx)	Remarks
cadmium	mg/l	0.01	0.005	1) In no instance should the pb-concentration exceed 0.3 mg/l after 16 hours contact with the pipes
cyanide	mg/l	0.05	0.1	
lead	mg/l	0.1 1)	0.05	
mercury	mg/l	-	0.001	
nitrate	mg/l	<50 2)	44	2) recommended
	mg/l	50-100 3)		3) acceptable
	mg/l	>100 4)		4) not recommended

Organic constituents of health significance (extract)

Constituent	Unit	Upper limit of concentration 1970 x)	Guideline value 1984 xx)	Remarks
aldrin and dieldrin	µg/l	no values decleared	0.03	
benzene	µg/l		10 1)	
benzo[a]pyrene	µg/l		0.01 1)	
carbon tetrachloride	µg/l		3 1)	tentative guideline value
chlordane	µg/l		0.3	
chloroform	µg/l		30 1)	
2,4-D	µg/l		100 2)	1) values computed from a conservative hypothetical mathematical mode
DDT	µg/l		1	
1,2-dichloroethane	µg/l		10 1)	
1,1-dichloroethane	µg/l		0.3 1)	2) taste and odour at lower concentrations
heptachlor and heptachlor epoxide	µg/l		0.1	
hexachlorobenzene	µg/l		0.01 1)	
gamma-HCH (lindane)	µg/l		3	
methoxychlor	µg/l		30	
pentachlorophenol	µg/l		10	
tetrachloroethene	µg/l		10 1)	tentative guideline value
trichlorethene	µg/l		30 1)	tentative guideline value
2,4,6 -trichlorophenol	µg/l		10 1)	0.1 µg/l odour

x) World Health Organisation: European Standards for drinking-water (Geneva 1970)
xx) World Health Organisation: Guidelines for drinking-water quality (Geneva 1984)

THE NECESSITY FOR DEVELOPING NEW TECHNOLOGIES AND THE ADAPTION OF EXISTING WATER TREATMENT PROCESSES TO NEW TASKS

The water treatment technologies used for the production of drinking-water will be confronted in the future with new and increasingly more difficult tasks.

In order to solve these problems, wide-ranging research work is necessary and the results are needed for adapting current water treatment processes to deal with new tasks and for developing new technologies.

Many of the different classical treatment processes which have been used in the past with great success are now unable to keep pace with the ever improving knowledge of the general hygienic and health-relevant factors which contribute to the requirements for drinking-water. These processes must either be modified or replaced by new treatment methods as exemplified in the following section.

THE PROBLEMS ASSOCIATED WITH THE OXIDATION AND DISINFECTION OF WATER WITH CHLORINE AND THEIR CONSEQUENCES FOR THE PROCESSING OF DRINKING WATER.

Until trihalomethane compounds were discovered in drinking-water, the use of chlorine as an oxidizing agent and disinfectant was an accepted standard technique in the practice of water treatment for many decades. In the future, at least oxidation with chlorine will have to be replaced with other oxidation techniques. In the Federal Republic of Germany it is to be expected that the use of chlorine as an oxidizing agent will no longer be allowed. Thus the uncontrolled formation of undefined chlorinated reaction products with organic matter present in the raw water will be impossible. This is particularly the case for breakpoint chlorination which in the past has been used successfully, for example, for the oxidation of ammonium. The simultaneous formation of chloramines is also unwanted.

Following the discovery that trihalomethane compounds can be formed when drinking-water is chlorinated, which also led to the significance of precursor substances for this process being realized and to the reaction mechanisms being partially elucidated, the whole field of treatment technology was suddenly brought into motion.

It is now very clear that the work of Rook (1974) and Bellar and coworker (1974) in which the formation of THM and its significance to drinking-water quality was discovered, marks the most fundamental turning point in the history of water treatment technology over the last 15 years.

The deliberate use of chloramine for disinfection as practised with the chlorine-ammonia treatment process should also no longer be allowed because monochloramines cause problems for dialysis patients with home dialysis equipment. For this reason, the limit for chloramine, measured as Cl_2, is 0.1 mg/l for dialysis water in the USA. In the Federal Republik of Germany, a limit for total chloramines will be set at 0.1 mg/l NH_4 for drinking-water. According to Althaus (1987) the presence of chloramines in drinking-water should generally be considered to be critical for human health. In biological tests with the bacterium Bacillus subtilis, monochloramine was found to be mutagenic. Moreover, it has also been shown that under certain, still not yet defined conditions, the presence of chloramine in the distribution system leads to nitrite being formed. The concentration limit for nitrite is 0.1 mg/l (EEC, 1980).

Thus the need for revising the disinfection processes is just as great as the need for a technically feasible removal of ammonium from water. When a treatment involving chlorine is excluded, other chemical means cannot be employed in water works under the present conditions. The only alternative is microbiological nitrification. This is a critical restriction in the available technical procedures.

FUTURE REQUIREMENTS FOR RESEARCH AND DEVELOPMENT

These are only a few of a large number of possible examples. They have the function of demonstrating that in the years to come there is a considerable demand for improvements in the field of water treatment technology which are associated with extensive research work. The first task is to work out the basic principles which are needed as the foundation for applied research so that new technologies can be developed or the present water treatment technologies can be modified. However, the more complicated and difficult these treatment process are, the more prone they are to failures.Thus equally important subjects of research are the development of monitoring methods and controlling processes which can be automated and operated by semi-skilled personnel. What is the use of a "hightech" treatment processing plant when it can only be run by highly qualified specialists.

In the following sections, these ideas will be illustrated with the help of some examples. The time available is by no means sufficient in order to be able to give a survey of all necessary research and development projects associated with this subject or which are within our powers of imagination.

Biotechnology

Biological treatment processes have a long tradition in the technology of water purification. Slow sandfiltration, soil filtration, bank filtration, dry filtration, iron and manganese removal are examples which instantly come to mind.

Overath and Haberer (1987) have published a noteworthy exposition on the state and perspectives of biological water treatment processes.

New ideas with which the current spacious and timeconsuming techniques can be optimized and further developed to compact processes are a promising foundation for the future. Particularly worthy of mention are:

- biotechnological processes which are carried out in fixed bed reactors and with which a high throughput rate can be achieved,
- nitrification of ammonium and ammonium compounds also at temperatures < 5° C,
- microbiological methods for the decomposition of organic compounds, in particular the resistant halogen-, sulphur- and nitrogen-containing organic compounds (e.g. pesticides!),
- combination of chemical oxidizing agents such as ozone or hydrogen peroxide with biotechnological degradation processes in fixed bed reactors,
- making use of the influence of trace elements, catalysts, enzymes and bioactivators,
- recognition and elimination of inhibitors or antibodies which are present in water and which repress the activity of microorganisms,
- building-up of special bacterial populations by the use of selection methods, mutation and gene manipulation as well as their use for specific purposes, when necessary after adaption. One must, however, be aware of the associated dangers.

This opens up a wide field of opportunities for future research and development work. Only little is known about the biology of the microorganisms which can be exploited for a multiplicity of different purposes.

The aim of future research is to run a bioreactor in such a way that an optimal development and metabolic function of the microorganisms can be achieved with the purpose of carrying out a precise reaction. The subjects of such research are:

- selection of the appropriate bacterial nutrition,
- creation of the optimum conditions for bacterial growth by finding the suitable
  - water temperature,
  - pH value and redox potential,
  - energy input,
  - retention time of the water in the bioreactor

  as well as
- the selection and development of the appropriate carrier material with regard to form, grain size and surface properties.

Unfortunately, relatively narrow limits exist for an optimization of biotechnological processes in the practice of water treatment.

For example, it is known that the nitrification of ammonium practically ceases at low water temperatures because the growth of the nitrifiers is too slow under these conditions. Ground filtration of water can also be influenced by this effect and an obvious decrease in nitrification can be experienced in winter when the underground passage is of short duration (a few hours to days). The winter period is also responsible for a distinct decrease in nitrification in waste-water treatment plants and in rivers and lakes which results in the appearance of the highest concentrations of ammonium in raw water (Fig. 1). Thus the drinking-water also contains elevated concentrations of ammonium which causes complications in disinfection processes with chlorine and disadvantageous effects to the health of particular groups of people (Althaus, 1987).

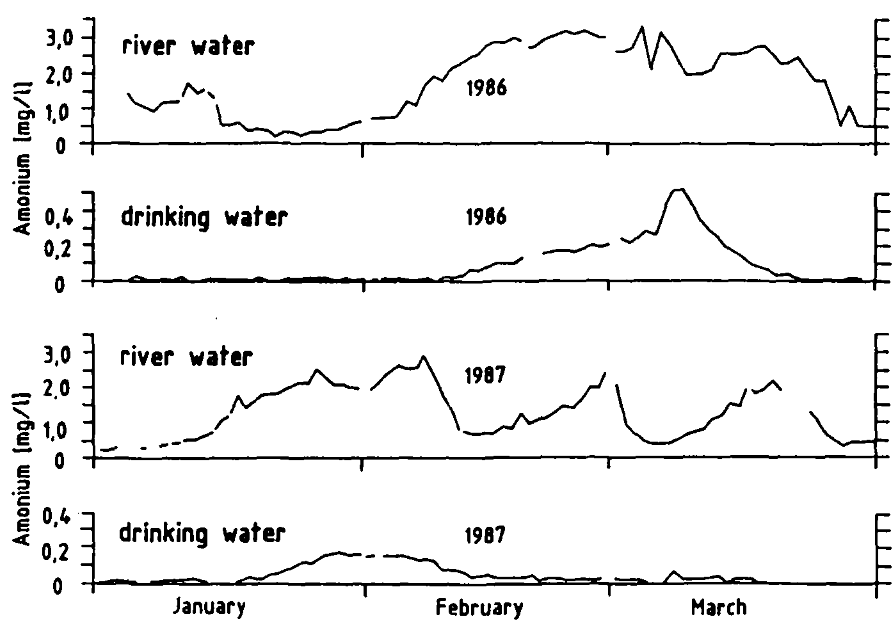

Fig. 1 Course of NH_4-concentration in the river water and the drinking water with drawn from it

There is no economical justification in increasing the water temperature in a water works. This parameter can, therefore, not be adjusted to meet the requirements necessary for optimizing the process. However, as can be seen from the results of our investigations, it is possible to create conditions which cause nitrifiers to grow as a biofilm with which an adequate nitrification rate can be accomplished at low water temperatures (≥ 0°C). Good ammonium elimination was achieved by means of nitrification in a submerged activated alumina filter in a pond which recieved the water from a fish rearing farm. The ammonium concentration in the raw water fluctuated considerably (0.03 - 3.7 mg/l NH_4, mean concentration 1.5 mg/l) and the pond was sometimes covered by ice (Fig.2 + 3). Elimination of ammonium amounted on average to 90%. It can be seen from Fig. 2 that the ammonium concentration was decreased by the denitrification process in the activated alumina from 1 - 3 mg NH_4/l to 0.02 - 0.05 mg NH_4/l independently of the water temperature (90% ammonium elimination at 2°C) (Bernhardt and coworker, 1981).

This brief example of a specific application has the purpose of pointing out that it is possible to eliminate ammonium with the help of a microbiological nitrification process and that it is also possible to use this process to achieve high elimination rates also at low temperatures. Furthermore it shows the reward of carrying out investigations on nitrification conditions in detail with regard to application for water treatment at a technical scale.

Narrow limits have been set to the large scale use of biotechnology in drinking water processing by the stringent requirements for drinking-water quality. The cultivation of large amounts of bacteria in a bio-reactor with the aim of exploiting microbiological processes with a high efficiency in a small volume must not impair the purity of the drinking-water from a microbiological point of view. Particular attention must be paid to this aspect with the use of specialized bacteria which in some cases have not been identified and which from the point of view of drinking-water supplies could present a risk to health which cannot be ignored.

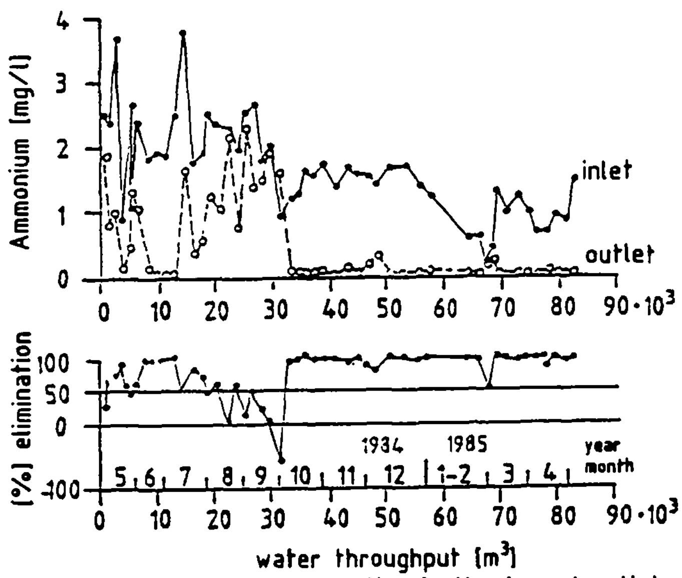

Fig.2 Course of the concentration in the in-and outlet of the activated Alumina -filter and the percentage elimination.

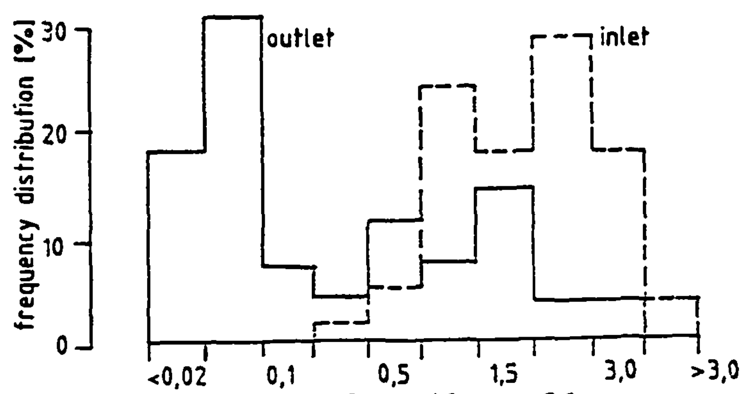

Fig.3 Frequency distribution of the NH_4-concentration in the inlet and the activated Alumina-filter-outlet.

This shows that detailed experiments and investigations must be carried out in order to find out which species of bacteria actually occur under technological conditions in the new biotechnological processes and whether they have a harmful effect on health.

The classical methods of bacteriological analysis of drinking-water must also be extended to encompass these new microbiological treatment processes.

On the whole, the field of biotechnology presents a promising and versatile source of possibilities for the future, but a great deal of basic research is still necessary before it can be said that this form of process technology has been mastered.

Advanced Water Treatment as the Basis for a new Disinfection Strategy

As in the past, research projects which are concerned with the disinfection of drinking-water are still of considerable importance. Of all the dangers to health which are associated with the drinking-water supply, decades of experience have shown that an inadequate disinfection of drinking-water has always led to a direct injury to health.

On the other hand, increasing knowledge of the reaction of chlorine with water-borne organic substances has led to a growth of resistance against chlorination steps in order to prevent a possible danger to human health brought about by the chlorination reaction products.

Thus the more the chlorination process in drinking-water treatment is being brought into discredit, the more acute is the danger and importance of an inadequate disinfection. However, on the whole the trend "Don't chlorinate your drinking-water" will be unstoppable in the future.

When one has the intention of limiting the use of chemical oxidants for disinfection or even finding alternatives for them, the required level of disinfection can only be achieved when advances water treatment is carried out. This demands extensive research and developmental work in the following fields:

- Development of disinfection methods which function reliably and which have a long-term effect without causing disadvantageous or undesired changes in the quality of the drinking-water.
- The development of new techniques or the application of already available technical principles in order to carry out advanced water treatment with the aim of producing a drinking-water, the quality of which is such that only low amounts of disinfectant are needed in order to arrive at satisfactory disinfection.
- Development of techniques which allow drinking-water to be processed without the need for a subsequent disinfection step.

A disturbance to disinfection is caused by:

- all types of particulate matter (organic and inorganic substances),
- dissolved organic matter,
- ammonium at a concentration above 0.1 mg/l when chlorine is used as a disinfectant.

Particulate matter

Particulate organic matter (phytoplankton, zooplankton, detritus) protects bacteria from attack by disinfectants. When chlorine or chlorine dioxide are used, this effect can be compensated for by increasing the dosage of disinfectant. It is, however, precisely this procedure which leads to an undesired impairment to the quality of the drinking-water. Moreover, particulate organic matter in the distribution system is a source of nutrients for bacterial growth and it is the cause of bacterial regrowth in drinking-water after disinfection.

Thus, of past and present importance is the necessity of improving the removal of particulate organic matter by the water treatment process. The currently known techniques e.g. flocculation, filtration, and under certain circumstances a subsequent membrane filtration technique, are by no means perfect enough to allow a 99 - 99.9% removal to be achieved. Progress is dependent on research into the effect which the structure and composition of peripheral cell wall of the target biomass has on the different separation steps involving flocculation and co-precipitation, filtration, flotation and, in certain cases, electrophoresis.

Dissolved organic matter

Dissolved organic matter of natural origin (humic and fulvic acids, algogenic organic matter) reacts with the disinfectants employed (Symons and coworker, 1981). Some of the reaction products are injurious to health (trihalomethanes), cause an impairment to the taste and odour of the water and consume disinfectant (Bernhardt and Hoyer, 1979) before its function as a bactericide has been fully effective (Jolley, 1985).

Redox processes take place which cause the disinfectant to be reduced. By this means more than 70% of the chlorine dioxide used is converted to chlorite which, similar to nitrite, has an effect on human health (Bernhardt and Klein, 1985). The concentration limit for chlorite in drinking-water in the Federal Republic of Germany is 0.2 mg ClO_2^-/l (N.N., 1986). In order to prevent such disturbances from occurring, water undergoing disinfection should not contain more than 1 mg/l DOC.

A far-reaching elimination of dissolved organic matter from raw water in the treatment process is in this connection an absolutely essential requirement in order to secure adequate and safe disinfection. This means that further development must take place in the fields of flocculation, filtration, ozonization and activated carbon filtration. It is also of considerable importance that new flocculants are synthesized which are specific for a definite application. Such tasks are, however, only possible when basic research in the chemistry of natural products is carried out with emphasis on the interactions occurring at the solid-liquid interface. The reactions of these polymers with the surfaces of the metal hydroxy-polymers must be further investigated in order to be able to remove more than 90% of these substances (expressed in DOC) from water by flocculation and filtration. At the present, 50% elimination is the best that can be achieved.

In this connection, it must be pointed out that the knowledge of colloid chemistry must be improved through basic research in order to bring about significant improvements in the efficiency of flocculation and floc removal. This includes more extensive research into the influence of the different substances and combination of compounds on the process so that it can be better understood and depicted. The aim of these investigations must be to move away from the empirical approach to water treatment with regard to flocculation and to start to make use of the different factors which have a decisive influence on the flocculation process. This is the case not only for the application of flocculants and flocculation aids, but also for being able to control flocculation by supplying the optimum pH value and energy input during destabilization of the colloids and agglomeration of the microflocs (Bernhardt and coworkers, 1986).

Furthermore, filters and filtermaterials have to be developed which allow a better retention of the flocs formed (f.e. Gimbel, 1986), and the use of a combination of different filter materials in multi-layer filters is a substantial topic for future research and development (Clough and Ives, 1986).

It is also of equal importance that all possibilities are exploited which lead to a decrease in natural organic matter already in the raw water. This means that, for example, eutrophication processes must be prevented by implementing appropriate measures of nutrient limitation. The demand that I have always put forward has received in this connection confirmation and a new dimension, namely that stagnant waters used for drinking-water should be in an oligotrophic or at the most in a mesotrophic condition but should never be eutrophic (Bernhardt, 1986).

Development of disinfection methods which are not based on the use of chemicals

Disinfection methods have to be developed which do not cause an undesired change in the quality of the drinking-water. Promising methods appear to be those based on physical principles, in particular disinfection with UV radiation. The large scale use of UV radiators to disinfect surface waters which receive sewage has by no means been exhaustively investigated. Many questions remain unanswered. For example it is not known whether photo-chemical reactions take place with the dissolved organic matter in the water which lead to the formation of compounds having a harmful effect on human health. There are already some indications that this occurs. It is also thought to be possible that a photochemical reaction causes nitrite to be formed from nitrate and the role of small amounts iron compounds as photoactivators has to be ascertained. In short, it must be determined which quality requirements a water must fulfill so that a safe disinfection with UV radiation can be carried out (Schenck, 1987).

Avoidance of disinfection with an adequately efficient advanced water treatment

If a water treatment process is carried out more extensively, it may be possible to dispense with disinfection. Assurance must be given at all times that the drinking-water complies with the regulations on the microbiological quality of domestic water supplies. When it is possible to supply drinking-water in this way, definite progress will have been made.

This necessitates the development of advanced water treatment techniques which have the main task of reducing the content of dissolved and particulate organic matter to a minimum residual concentration (turbidity $\leqslant$ 0.05 FTU, DOC $\leqslant$ 0.5 mg/l C, $NH_4 \leqslant$ 0.1 mg/l).

In well protected ground water resources a water can be drawn which is of such good quality that disinfection is unnecessary. This is the case for numerous water works supplying larger cities e.g. Munich and Berlin.

Intensivated flocculation and filtration processes allow a 99 to 99.9% elimination of coliform bacteria to be performed, as demonstrated by our studies at the phosphorus elimination plant. This shows that it is possible to remove bacteria with a high degree of efficiency using flocculation and filtration techniques (Bernhardt and coworkers, 1985).

This is not a utopian demand. It can be achieved within the next decade when research and development is carried out within this field of water treatment. However, the goal can only be achieved when simultaneously more effort is taken at protecting the water resources from anthropogenic contamination.

Monitoring and Controlling the Water Treatment Processes

Complicated water treatment processes of high efficiency are sensitive to fluctuations in the raw water quality and peripheral influencing factors. When they are expected to operate with a high performance, they must be subjected to continual surveillance. A water treatment plant can, therefore, only be operated satisfactorily when a high degree of automation is included in the control and regulation processes concerning different variables e.g. chemical dosage, pH value, redox potential, hydraulic, energy input, etc. Particularly when the raw water undergoes rapid and great changes in quality, the operators of such plants even when well qualified would not be able to cope with changing situations without the help of of automated processes.

The development of process control techniques is a long-term activity which requires even more extensive basic research and the development of measurement and control equipment coupled with considerable effort in the field of computer handling of information. The first promising beginnings are already discernable with flocculation and filtration, activated carbon filtration and ozonization. An integral part of this activity is the development of novel methods of water analysis using equipment which is not in direct contact with the water.

Ives (1987) has developed a strategy for future research which is involved with the measuring and controlling of water quality with sensors which do not require immersion i.e. non-invasive sensors. These sensors, which are still in the experimental stage, have the advantage that they do not become fouled and are, therefore, particularly suitable for monitoring of raw water and controlling a fully automatic water treatment works. They are based on the principle of the reflection of beams of the complete electromagnetic spectrum from the water surface, the refraction of light in the medium and the reflection of sonic waves. These methods allow the concentrations of turbidity-producting substances, cations and anions, organic matter (as DOC) and the movement and growth of particles during the flocculation process etc. to be measured. The development of these measuring methods has only just begun and necessitates extensive and interdisciplinary research. The first successfull results (Hilton, 1984; Defebre et al. 1985; Smeuders et al. 1983; Warman at al. 1984) show that these methods of monitoring are feasible.

CONCLUSION

The above-mentioned research projects are a result of the task which has been set to guarantee a satisfactory supply of drinking-water in industrialized countries until the year 2000. They reflect the development of a highly technical process engineering.

There is, however, an equally great demand for research into the development of very simple but very efficient water treatment processes which can be applied in areas of developing countries where there is no electricity, no elaborate flocculants, no ozone and no activated carbon, but where water treatment must be carried out with indigenous products and naturally occurring materials. With decreasing chances of being able to use appropriate technologies, the more one has to use experience and creativity in order to be able to secure a drinking-water supply with the available means. This demands that research is conducted on an even wider basis, because even in these countries certain requirements are placed on the quality of drinking-water and they must be fulfilled in order to prevent drinking-water from being a source of illness. The fulfillment of this task is a great challenge to the research establishments of the industrialized countries which are occupied with water research.

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EMERGING TECHNOLOGIES IN THE WATER SUPPLY INDUSTRY

James F. Manwaring, P.E.
Executive Director
AWWA Research Foundation
Denver, Colorado, USA

ABSTRACT

This paper reports on two seminars sponsored by the AWWA Research Foundation, which were held in 1984 and 1986. The seminars were designed to identify technologies emerging within the water supply industry. Eleven countries contributed to the first seminar proceedings while the second attracted representatives from 15 countries. The paper examines the differences and similarities among the research programs among the various countries as well as the change in the general research priorities within the industry between 1984 and 1986. Based upon these results and the Foundation's own experiences some projections are made regarding the direction of future water supply technology.

KEYWORDS

Emerging technologies; organics; ozone; corrosion; disinfection; biological treatment

INTRODUCTION

The American Water Works Association Research Foundation (AWWARF) has sponsored two seminars directed at technologies emerging within the water supply industry. The first invitational meeting was held in 1984 and brought together representatives from eleven countries; the meeting was held in Amsterdam with KIWA acting as the local site host. The second three-day seminar, hosted by the Water Research Centre, was held in Oxford, England in 1986 and attracted representatives from fifteen countries.

The common objective of the two meetings was to identify emerging technologies or innovative developments in all aspects of the water supply field. By exchanging information among the participants, it was thought that the group might discover promising ideas that merit further investment. In addition, it was anticipated that such exchanges could lead to cooperative ventures and reduction of duplicative efforts among the participants.

AWWARF participates in joint research programs where the specific project has equal participation by, and benefit for, the involved parties. These activities range from direct research efforts, such as the taste and odor study presently being jointly sponsored by AWWARF and Lyonnaise des Eaux, to the preparation of state-of-the-art reports. Examples of the latter include the AWWARF/KIWA report on the removal of organic contaminants and the AWWARF/Engler-Bunte Institute's report on the internal corrosion of water systems. The "Emerging Technologies" effort is another example of a cooperative and collaborative effort.

The AWWARF effort differs from the "Water 2000 Conference" in several respects. First, the AWWARF seminars concentrated solely on drinking water, but covered all aspects of the topic, including resources, planning, treatment, distribution and management as opposed to focusing upon technology and microorganic contaminant removal. The design of the Foundation's seminar did not identify any priority topic but several issues did emerge as common concerns and topics. Secondly, the output from the seminars was distributed only to the attendees since its most obvious use was for research planning purposes. In many ways the "Water 2000 Conference" is the perfect complement to the seminars by serving as a vehicle for disseminating the information throughout the international community. The conference will also provide a wider examination of the current technological direction of the water supply industry.

APPROACH

The first collaborative effort was attended by representatives from Belgium, Canada, France, Italy, The Netherlands, Norway, Spain, Switzerland, United Kingdom, United States, and West Germany. The resultant product was a notebook containing 161 individual project descriptions as submitted by the participants and edited by AWWARF. Denmark, Finland, Japan, U.S.S.R., and Sweden were added to the list of participants for the 1986 seminar. However, the number of project descriptions included in the seminar proceedings was trimmed to 109 by focusing attention on field scale technologies.

The seminars were preceded by several months of data collection, report preparation, and review by the participants. The project descriptions were entered on a standard form and sent to AWWARF along with extensive documentation. The Foundation's staff organized the material and compiled a workbook containing a brief description of each project and selected background information. Information distributed on every project included a description, development status, operational and cost data, and places of installation.

Table 1 shows the individual titles of the Oxford meeting projects as submitted by each country, under ten basic headings. By comparison, Table 2 categorizes the 161 project descriptions that were submitted for the first meeting in 1984 into the five general categories. These readily demonstrate the first major difference between the two seminars. The first collected data on general topics while the second focused on specific aspects of water supply treatment and operation. It must be emphasized that this body of information is a representative sample of the research being conducted by the countries participating in the seminars, not an all-inclusive collection.

OVERVIEW

In general, research and development associated with new treatment technologies highlighted both of the seminars; however, optimization of existing unit processes emerged as the guiding, practical theme--driven by mutual concern for water quality, operational costs and the national economies. The majority of optimization projects focused on modifications to improve conventional treatment efficiencies, remove source contaminants and reduce treatment by-products.

It was a consensus of the two sessions that growing demands and limited water resources, in an increasingly contaminated and populated environment, will require not only reduced consumptive patterns and utility loss control programs, but also responsible and resourceful management by the contributors of hazardous and deleterious wastewaters. This perspective merely reinforced the knowledge that water supply resources are intricately tied into other environmental control programs and that comprehensive planning necessarily considers all aspects of the environment.

As previously indicated, the 1986 conference proceedings contained descriptions of 109 projects directly related to water treatment processes and operations. Coincidently, the 1984 seminar also contained 109 project descriptions in this general category of research and development. While this analysis will focus on these 218 projects, some mention is necessary regarding the general characteristics of the 52 projects from the 1984 conference that will not be included. In that first conference, several groundwater issues were discussed including techniques for in situ treatment, recharge and aquifer protection. Automation of water system components and the evaluation of water conservation techniques, including various pricing structures, were important topics.

Figure 1 shows the distribution of the 1984 and 1986 project reports among the 10 topic areas within the general category of water treatment. It is readily apparent that in both seminars that organics control and removal was the single most popular research topic, closely followed by water monitoring and analysis. These topics, plus ozonation, composed 50 percent of those projects discussed.

The application of biological processes to the treatment of drinking water is a topic that seems to be capturing an increasing share of interest. Several countries prepared a summary of biological treatment for nitrate removal, including a mix of heterotropic and autotrophic processes. More conventional topics like flocculation, sedimentation, and filtration continue to draw significant interest as do corrosion and water quality in distribution systems. Also of interest are the treatment processes designed to deal with special problems such as the removal of radon or iron and manganese. A brief discussion of each of the main topical areas follows.

Control and Removal of Organics

Projects involving organic contaminants received the greatest attention. Work continues on the use of air stripping for the removal of volatile contaminants and on the study of granular activated carbon as a treatment technique. The latter includes the effects of substituting GAC for conventional sand media and the full-scale demonstrations of GAC performance and the regeneration of carbon. There seems to be an increasing interest in the application of carbon and other methods to control odors, especially the earthy/musty odors that are not removed in conventional water treatment. Powdered carbon continues to be considered as a treatment alternative, and computer models and databases are now actively being used to evaluate options for organics removal.

One general observation is that the European water supply community seems to be directing its attention toward a broad spectrum of micro-organic contamination as opposed to the American focus which is on individual organic compounds. For instance, the U.S. has a great deal of research directed at the removal of specific contaminants such as trichloroethylenes, trihalomethanes, etc. whereas the European countries seem to be investigating technologies directed at the organics problem as a whole. Bank infiltration, reinfiltration, and in-ground storage are just a few examples of European technology designed for the wide spectrum of organic contaminants.

Monitoring and Analysis

Developing techniques for more effectively and promptly assessing water quality and for determining the effectiveness of treatment processes is a subject of special and long-term interest. Over the past twenty-five years the Europeans have developed and utilized rather sophisticated fish sensors to monitor the quality of their surface water supply and control their intakes accordingly. System variables among the British, Swiss, Dutch and Canadian projects included: simultaneous water quality analyses, fish species and function to monitor, portability, water sampling, alarm and control strategies.

Mutagenic testing of water--both raw water and finished drinking water was a widespread practice in Europe in 1984--a practice that was being picked up in the U.S. and Canada by the time of the 1986 seminar. Data are being collected as background information and as a gross measure of contamination. While all agree that there is no meaningful interpretation of single results, mutagenicity is being used as an indicator signaling the need for more detailed follow-up and analysis.

Monitoring equipment received a lot of attention, including equipment and techniques for assessing turbidity, corrosion by-products, organics in groundwater, phosphorus, and coliforms. The use of laser fluorescence and fiber optics to monitor in situ organics in groundwater as reported in 1986 demonstrates how monitoring and analysis continue to be the technological edge in the water supply industry.

Ozonation

There has always been a special fascination with the application of ozone technology in water treatment since its first use in 1906 in Nice, France. The increase in the number of problems from 1984 to 1986 is a reflection of the American interest in the use of ozone as a means of controlling trihalomethane production. The utilization of ozone is increasing in the U.S. as evidenced by the ozone facilities being included in the new treatment plants for Los Angeles and Hackensack, New Jersey.

Research on ozonation also appears to indicate an increasing interest in using ozone as a pretreatment prior to coagulant addition. This application is a departure from traditional water treatment theory, which generally suggests that ozonation be postponed until the later stages of the process where the demand for ozone has been minimized. Projects covered the development of more efficient devices for contacting ozone with water, better devices for monitoring ozone, information on ozone resistance of materials, and the application of ozone prior to groundwater recharge.

Selected Treatment Problems

Research continues into special treatment problems, the removal of unusual contaminants, and the development of unique, specialized processes. A number of treatment techniques were discussed for handling special problems such as the removal of chrome, fluoride, radon, and radionuclides.

Water quality problems associated with iron and manganese in groundwater appear to be ubiquitous and different techniques are being investigated. In Holland and Sweden for instance, as well as on Long Island in the U.S., a process utilizing injected water and/or air is being employed to generate in situ oxidation of iron and manganese in the aquifer. Norway is investigating the use of reinfiltration as a natural means of removing these elements. Studies in the U.S. and Canada are focusing on the simultaneous addition of sodium silicate and chlorine to sequester the iron and manganese.

Flocculation/Sedimentation/Filtration

Flocculation, sedimentation, and filtration are the core of our current water treatment technology so it is not surprising that research on improving and optimizing these processes was an important topic in both seminars. In Oxford, the Soviet representative outlined the technology used for high turbidity waters, the use of two-stage filtration as a treatment technique for highly colored waters in cold climates, a special package unit for treatment of groundwaters called "STRUYA," and the technology used by the City of Moscow at the Eastern Waterworks. Other studies included the optimization of polymers in filtration, air-assisted backwashing and the use of tracers in water treatment facilities.

The water quality and operational problems associated with small water supply systems are a world-wide concern. The primary objective of small system research can be stated as the development of technologies that have low capital cost, low chemical usage, low operational costs, minimal operational requirements, and low sludge production. As impossible as it would appear to simultaneously meet these objectives, many countries are investing a great deal of money in an effort to do so.

Corrosion

Corrosion and its impact on the quality of water in distribution systems and in consumer plumbing, though among the oldest topics in the water field, continue to be subjects of interest. Every country, without exception, is investing heavily in the control and resolution of corrosion. Several researchers are involved in attempting to develop a better surrogate parameter than the current indices while some are focusing on the measurement and reduction of specific corrosion by-products. All agree that corrosion is probably the most pervasive economic problem facing the water supply industry today. However, it is an extremely complex phenomenon that requires site-specific investigation; research is just beginning to unravel the many competing and synergistic factors involved in corrosion. Because of the recent release of data regarding the toxicity of lead in drinking water, it is expected that research activity in this area will increase significantly.

One of the emerging problems mentioned by several representatives was bacterial regrowth in water distribution systems. Water supply systems in Belgium and Holland are just beginning to study the cause of such regrowth and factors which control it. Outbreaks of regrowth in several U.S. water systems have caused a re-examination of the basic premise of post-treatment disinfection. It appears to be one of the common areas of future exploration.

Biological Treatment/Denitrification

The application of biological processes to treatment of drinking water is an area of growing interest. This meeting saw a variety of presentations on the topic, many focused on the problems of small water systems. While the Europeans have studied and utilized biological treatment, particularly for micro-organics and nitrates, the process has been deliberately neglected by the American research community. Operational denitrification facilities in England, France and Germany appear to be both efficient and effective. The Swiss are involved in in situ biological denitrification while the Germans are experimenting with the decontamination of groundwater by treatment with ozone to enhance biological degradation and reinjection. Bank infiltration which utilizes the natural biological purification process has been practiced in West Germany and Holland for several years; the usefulness of the process is now being investigated at New Orleans and Louisville in the United States.

Disinfection and Microbiology

Like corrosion, disinfection and the effective control of microbiological impacts in water systems are topics that have long been with the drinking water industry. We continue to learn more about these topics through research, but one of the major problems (by-products of chlorination) persists. Several countries are working to eliminate the chlorite problem inherent in the production of chlorine dioxide, including a German device to produce pure chlorine dioxide and a Belgian continuous monitor for residual chlorite. There has been, and continues to be, a great deal of work in the U.S. on trihalomethanes--specifically the reduction of TTHMs while maintaining the bacteriological integrity of the distribution system. The common approach has been the continued use of chlorine as the primary disinfectant but in a manner which minimizes the production of TTHMs; for example, using combined chlorine, changing the point of chlorination and improving flocculation are just a few of the methods being utilized at operational treatment plants.

Although much needs to be learned about reuse and some of the projects currently underway represent major investments (e.g., the Denver reuse project, Water Factory 21, and the Yuma Desalter), it would appear that these topics are not subjects of growing interest to the water industry at the present time. The cost of many of these processes may be one of the major factors hindering increased activity, together with a cautious attitude where the public health is concerned.

Conclusions

The data compilation resulting from the two seminars sponsored by AWWARF afford an opportunity to draw some comparisons between the research and directional priorities of the drinking water industry of the various countries. Attendees at the conferences were unanimous in their opinion that meetings of this kind do a great deal to facilitate the effective exchange of up-to-date information on water research activities. Each participant came away from the meetings with a number of ideas for his or her situation. Each country has its unique research agenda, but it is clear that meetings like this one will allow every program to be more broadly conceived and effective. Accordingly, AWWARF has finalized plans to sponsor another workshop to be held in the spring of 1988 and all interested organizations are invited to participate.

FUTURE

The future changes in the water supply industry will be a combination of "need pull" and "technology push." In the past few decades, data indicate that approximately seventy-five percent of new products or developments are a result of an identified need--such technology is more oriented to the market and as a result, the chances for successful research and development are much improved. On the other hand, "technology push" has made and will continue to make, a large impact on the water supply industry, particularly in the areas of computer technology and analytical developments.

Priorities will continue to be driven by the desire to develop practical solutions to the needs of water suppliers. In the U.S. these needs will be initially defined by the new water quality regulations imposed by the 1986 Safe Drinking Water Act Amendments. Eventually, and before the year 2000, the water supply industry in the U.S. will replace this regulatory induced climate of water quality definition with one of collaborative and mutually defined goals and objectives. This will be accomplished through the industry's own research and development effort which will allow it to become proactive instead of reactive. In this respect, collaborative research and development, between the government and the industry within a country and among various industry organizations of different countries, will become more common as the worldwide water supply industry seeks ways to maximize the utilization of the limited research resource.

The year 2000 will not alter the consumer's attitudes toward their drinking water quality--the chief criteria of customer acceptability and satisfaction will continue to be the taste and odor of the water. Unless a major marketing effort is launched the human consumption of drinking water (62.4 gallons/capita in the U.S. in 1962 and 41.2 gallons/capita in 1986) will continue to decline. While a small percentage of this decline can be related to consumer concern of their water supply, the extensive marketing of soft drinks in the U.S. is seen as the primary factor. Soft drink consumption in 1986 was 42.1 gallons/capita---the first year that its consumption had exceeded that of drinking water.

Treatment Technology

All areas of treatment will undergo changes in the next thirteen years. The discovery of disinfection by-products has already changed the industry's philosophy toward the unrestricted use of chlorine and it is expected that this trend will continue. Research is already underway on technologies that inherently contribute nothing to the water. Ultraviolet disinfection has been practiced for many years. Laser techniques have advanced to such an extent that such water supply applications may be economically possible within the next decade. Membrane filtration for sterilization purposes is already practiced in the pharmacutical and food processing industries.

The membrane disinfection process could be easily incorporated into a low-pressure reverse osmosis treatment plant further reinforcing the concept of physical separation without utilizing direct additives in treatment scheme. Ultrafiltration or reverse osmosis could be used following microfiltration of various pore sizes to remove suspended particles and a portion of the organic material. New adsorbents are likely to be designed for a particular class of compounds and for easy regeneration.

Sludge treatment and disposal will become more of a problem in the future than now. The increasingly stringent regulations regarding the disposal of hazardous waste, associated with the liberal definition of "hazardous," will force the industry to critically evaluate alternate means of disposal and volume reduction.

Biological treatment will increase in popularity in the water supply arena. While iron and nitrate treatment are already practical applications of biological treatment, further advances will be related to genetic engineering of bacterial species for specialized application such as in-situ destruction of a known groundwater contaminant.

The optimization of existing water treatment processes and their integration with new technologies will remain a major priority for the industry. The huge investment in existing facilities prevents the industry from immediately embracing and installing new techniques without integration.

Instrumentation

It has been projected by the Hudson Institute that the changes that will occur in the next 20 years will be five times greater than the number of changes experienced by mankind in the last 100 years. And the majority of these changes will be the result of the application of the computer.

Water treatment is no different. The magnitude of change that is expected in the area of instrumentation is expected to be tremendous. Knowledge-based expert systems (KBES's) will become commonplace in the industry for the operation of treatment plants, reservoirs and distribution systems. By providing expertise that may not otherwise be available, an expert system has the potential to reduce cost and improve water quality through more efficient operation.

Technology Transfer

Although the water supply industry is not expected to develop new communications systems and techniques, it must be ready to embrace the ones that become available. Research and development require large commitments from sponsors and those supporters must see the application of results if that commitment is to continue. The transfer of technological developments from the research arena to the waterworks is essential to demonstrate the investment return available from the implementation of new ideas and concepts.

Toxicology

The professionals within the water supply industry have a responsibility to increase their understanding and knowledge of the toxicological characteristics of drinking water contaminants. It is critical that the industry develop the capability of identifying the compounds, and mixture of compounds, important to the health of consumers. The assessment of risk and translation of that risk into standards is too important to leave solely in the hands of the federal government. The public policy debate over how much cancer risk should be permitted or tolerated in drinking water will certainly continue. The factual basis, however, must become a more secure basis on which to construct those policies of public health protection.

TABLE 1 Projects Reviewed at Emerging Technologies Conference, Oxford, England, April 1986

CONTROL AND REMOVAL OF ORGANICS

CANADA-Full-Scale Use of Granular Activated Carbon at the Buffalo Pound Water Plant (Regina/Moose Jaw, Saskatchewan)
-Trace Organic Contaminant Removal by Conventional Treatment with Add-On Activated Carbon in the Post-Contactor Mode
-A Study Using Computer Software to Model the Performance of Carbon Adsorbers in a Large Canadian Drinking Water Treatment Plant
-Distribution of Trihalomethanes and Total Organic Carbon in Pilot Scale Granular Activated Carbon (GAC) Columns
-Development of a Computer Aid Program for Trace Contaminant Removal From Drinking Water in Ontario

JAPAN-Experiment for the Reduction of THM and Musty Odor by Ozonation and Granular Activated Carbon Treatment With Pilot Plant and Demonstration Plant

NETHERLANDS-Removal of Methane With Aeration Treatment
-Removal of Volatile Organic Substance by Aeration

NORWAY-Removal of Medium Levels of Aquatic Humus Using Two Stage Direct Filtration

SWITZERLAND-Evaluation of Granular Activated Carbons on Pilot Scale

UNITED KINGDOM-Removal of Volatile Organics by Aeration

UNITED STATES-Evaluation of Substituting Granular Activated Carbon for Sand Filter Media
-Field Scale Evaluation and Optimization of Granular Activated Carbon and Air Stripping Systems
-Granular Activated Carbon Removal of Pesticides (DBCP, EDB, and TCP) in the Parts Per Trillion Range From Ground Water
-Monitoring and Controlling Tastes and Odors in Philadelphia's Drinking Water
-Treatment of Drinking Water by Bromide Addition and PAC Adsorption

WEST GERMANY-Powdered Carbon Filtration
-Two-Stage Fluidized Bed Incinerator for Reactivation of Granular Activated Carbon

MONITORING AND ANALYSIS

CANADA-Drinking Water Surveillance Program (DWSP)

JAPAN-Determination of Various Phosphorus Forms in Water and Wastewater by Automatic Analyzer

NETHERLANDS-Detection and Evaluation of Mutagenic Activity in Drinking Water
-Organic Halogen Determination (OCl, OBr and OI)
-Automated Isolation and Sample Preparation for the Chemical and Toxicological Analysis of Organic Compounds in Water
-Easily Assimilable Organic Carbon (AOC) in Drinking Water

SWEDEN-Monitoring Equipment to Determine the Effect of Water Quality Variations on Copper and Iron Corrosion

SWITZERLAND-Continuous Monitoring of Several Quality Parameters of a River's Water
-Spectrophotometrical Determination of Chlorine Dioxide and Chlorite Side by Side by Means of Two Different o-Tolidin Solutions

UNITED KINGDOM-Analytical Services Program (ASP)
-Assessment of Analytical Performance Using Check Samples
-Analytical Methods for Nonvolatile Organics in Water

UNITED STATES-A Very Low Range Turbidimeter for Laboratory and Process Monitoring
-A High Range Turbidimeter for Monitoring and Controlling the Backwashing of Filters
-In Situ Detection of Ground Water Contaminants Using Laser Fluorescence and Fiber Optics
-Detection of *Escherichia coli* and Coliforms Directly From Water Utilizing Hydrolyzable Substrates

OZONATION

CANADA-Pilot Studies in the Use of Ozone for Domestic Water Treatment

FRANCE-Technology of Applying Ozone Before Direct Filtration
-Ozoneurs Moyenne Frequence (Medium Range Ozonators)
-Monitoring an Ozonation Process Through an UV Absorbance Measurement
-Development of a New Ozonation Reactor: The Deep U Tube

SOVIET UNION-Potable Water Ozonation Experience in Moscow
-Fume Cleaning From Residual Ozone

UNITED STATES-Evaluation of Pre-Ozonation/Deep Bed Filtration With GAC in Water Treatment
-The Contra Costa Process
-Use of Ozone and Diatomaceous Earth as a Water Treatment Process
-The Los Angeles Aqueduct Water Treatment Plant
-The Use of Nonalloyed Ferrous Metals in High Concentration Ozone Environments

WEST GERMANY-Cleaning of Ground Water Through Partial Reinfiltration of Water After Ozone Treatment and Oxygen Enrichment
-"The Mulheim Process" for Treating River Waters by a Combination of Ozonation and Biological Treatment in Granular Activated Carbon Filters

SELECTED TREATMENT PROBLEMS

BELGIUM-Process for Purifying Waters Contaminated by Nuclear, Biological, or Chemical Agents to Produce Emergency Supplies of Drinking Water
-Recovery of Chromates From Rinsewater

CANADA-Iodine Suppression of Biological Sulphide Formation in Hot Water Tanks
-Combined Chemical and Biological Evaluation of Drinking Water Treatment Alternatives

DENMARK-Pure Oxygen Aeration of Groundwater

FRANCE-Hexavalent Chromium Removal From Potable Water

JAPAN-Iron Removal System of Ground Water Under the Catalyzing Filtration Process

SOVIET UNION-New Technologies for Treatment of Water From Different Sources for Drinking Water Supply in the USSR

UNITED KINGDOM-Effect of Water Treatment on the Mutagenicity of Drinking Water

UNITED STATES-A Mobile Drinking Water Treatment Research Facility for Evaluating Inorganic Contaminant Treatment Methods
-The Nalgonda Process for Defluoridation of Drinking Water
-Radon Removal Techniques for Community Water Supplies
-Computer Assisted Preliminary Design for Drinking Water Treatment Process System

FLOCCULATION/SEDIMENTATION/FILTRATION

FRANCE-New System of Settling: The Densadeg
-Water Clarifiers Using Microsand

JAPAN-Application of Fuzzy Reasoning to the Water Purification Process

SOVIET UNION-The Intensification of a Rapid Filter Wash Process by Means of Air Fed Above the Filter Bed
-Technology of Water Treatment: East Waterworks, City of Moscow
-Water Treatment by Two Stage Filtration
-"Struya" Units for Surface and Ground Water Treatment
-High Turbidity Water Treatment

UNITED STATES-Using Polymers With Direct Filtration
-Plant Hydraulics Study Using Fluoride Tracer

CORROSION/DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE

CANADA-Restoration of Flow Capacity in Copper Water Services
-Alum Treatment of Watermains to Minimize Iron Leaching Off Newly Scoured Surfaces

DENMARK-Carbonation of Low Alkalinity Using Carbon Dioxide Formed by Propane Downburners

FRANCE-Optimal Operations of Large Water Supply Networks

NETHERLANDS-Conditions of Tap Water

NORWAY-Development of Mobile Monitoring Equipment for Corrosion in the Distribution System

SWEDEN-Protection of Pipes Against Corrosion
-Alkalizing Filters for Installation in the Well

UNITED KINGDOM-Plumbosolvency Control of High Alkalinity Potable Waters

UNITED STATES-Maintenance Issues in Water Supply Distribution Systems
-Predicting Water Quality in Distribution Systems

BIOLOGICAL TREATMENT/NITRATE REMOVAL

FINLAND-Biological Methods in Small-Scale Water Treatment

FRANCE-Biological Deferrization and Demanganization
-Biological Removal of Nitrates (The Case of Small Facilities for Treating Well Water)

JAPAN-Biological Pre-Treatment of Dissolved Substances in Raw Water
-Biological Oxidation System on Fluidized Medium as Pre-Treatment System for Polluted Raw Water to a Water Purification Plant

NETHERLANDS-Underground Iron Removal From Ground Water
-Denitrification of Groundwaters With the Sulphur/Limestone Process

SWITZERLAND-Denitropur: Denitrification of Drinking Water With Hydrogen Oxidizing Bacteria

UNITED STATES-Removal of Nitrate From Well Water

WEST GERMANY-Upflow Filtration for Nitrification, Denitrification, and Iron and Manganese Removal

DISINFECTION AND MICROBIOLOGY

BELGIUM-Disinfection by Combined Treatment With Monochloramines and Hydrogen Peroxide

CANADA-Incidence of *Legionella*, *Aeromonas*, and *Campylobacter* in Municipal Source Water and Treated Drinking Water

DENMARK-Preformed Monochloramine for Disinfection

NETHERLANDS-Side Effects of Post-Chlorination

SOVIET UNION-On-Site Electrolytic Production of Sodium Hypochlorite for Disinfection of Water

UNITED KINGDOM-On-Site Electrolytic Chlorine (OSEC) Plant for Disinfection of up to 55 ML/d

UNITED STATES-Reduction of Chloro-Organic Disinfection By-Products by Alternative Disinfectants

DESALTING AND REUSE

JAPAN-Project of Sewage Reclamation System for Re-Use by Applying Magnesia Adsorbent M-511

UNITED STATES-Yuma Desalting Plant
-Denver Potable Reuse Demonstration Project
-Water Factory 21 Membrane Research Project

OTHER RESEARCH ACTIVITIES

NETHERLANDS-Recharge Wells
-Improvement of Water Quality During Storage in Reservoirs
-Development and Application of the Modified Fouling Index as a Measure of the Fouling Potential of Water to be Injected by Injection Wells

UNITED KINGDOM-Water Quality Indices

UNITED STATES-Toxic Screening Models for Water Supply

TABLE 2 Projects Reviewed at Emerging Technologies Conference, Amsterdam, The Netherlands, October 1984

WATER RESOURCES

CANADA-Water Supply Reliability and Risk

NETHERLANDS-Recharge Wells

SWITZERLAND-The Most Up-To-Date Groundwater Management by Means of Process Computers Explained by the Example of the Groundwater Plant Hardhof, Zurich
-Progressive Water Tariff as Incentive to Water Saving
-Supplying Water to Small Communities and Entities From a Central Regional Water Production Facility
-Tariff Measures and Operational Possibilities for the Restriction of Specific Water Consumption

UNITED KINGDOM-Intake Protection Systems
-Water Well Development Rehabilitation
Catchment Quality Control

UNITED STATES-In-Reservoir Chlorophyll Monitoring as a Reservoir Management Tool
-Multiple Water Supply Approach for Urban Water Management and Alternative Technologies for Small Water System Management
-Water Audit Guidelines for Conservation and Management
-Laser Mapping

WEST GERMANY Groundwater Enrichment With Pretreated Surface Water

WATER TREATMENT AND OPERATIONS

BELGIUM-Package Treatment for Purifying Water Heavily Contaminated by Nuclear, Biological, or Chemical Agents
-Development of a Continuously Operating Analyzer for Monitoring Residual Chlorite in Water
-Photochemical Generation of Ozone
-Optimization of Activated Silica Preparation
-Optimization of Chlorine Dioxide Generation for Post-Disinfection
-Preozonation as an Aid in Flocculation-Filtration

CANADA-Sequestering of Iron and Manganese. Treatment of Contaminated Groundwater
-Reducing Trihalomethanes in Finished Water
-Organics Removal by Conventional Treatment Add-On Activated Carbon Treatment and Aeration

FINLAND-Biological and Chemical Removal of Iron and Manganese From Groundwater Larger Systems

FRANCE-Monitoring and Ozonation Process Through UV Measurement
-Development of a New Ozonation Reactor The Deep U Tube
-Biological Aerated Filters or Biocarbone*
-Chromium Removal From Groundwater
-Biological Denitrification of Groundwater
-Use of Prepolymerized Al-OH Solutions as Primary Coagulant/Flocculant
-Computerized Control and Total Automation for a Drinking Water Treatment Plant of 180,000 m3 per Day

ITALY-The Use of Solar Energy to Power Remote Pumping Stations
-Water Reuse Through the Rim-Nut Process
-Removal of Organic Halocompounds in Drinking Water by Aeration Air Stripping and Activated Carbon GAC
-Anaerobic Treatment of Concentrated Wastewaters
-Advanced Precipitation Processes for Heavy Metals Removal From Wastewaters
-Deozonation With Hydrogen Peroxide
-Dechlorination With Hydrogen Peroxide

NETHERLANDS-Side Effects of Postchlorination
-Removal of Methane With Aeration
-Removal of Volatile Organic Substance by Aeration
-Underground Iron Removal From Groundwater

NORWAY Humic Substance Removal by Ion Exchange
-Humic Substance Removal by Reverse Osmosis
-Electrocoagulation for Removal of Aquatic Humus From Drinking Water
-Guidelines for the Planning, Construction and Operation of Submarine Pipelines for Water Supply and Sewage

SWEDEN-Contact Filtration Using AIB Filters
-Alkaline Media Filter for Installation in the Pipe System Small Systems
-Purac's FLOOFILTER*
-Dynasand Continuous Sand Filter
-Vyredox, In Situ Purification of Groundwater

SWITZERLAND-Simple and Compact Process Unit for Iron Removal From Anaerobic Groundwaters
-Treatment of Karstic Spring Waters Containing Chlorinated Hydrocarbons
-UV-Water Disinfection for Large Flow Rates
-Oxidation of Organic Matters Using UV in Conjunction With Hydrogen Peroxide
-In-Ground Biological Denitrification of Groundwater
-Production and Application of High Ozone Concentrations in Water Treatment Plants
-Covering the Surfaces of Enrichment Basins and Slow Filters With Fleece-Mats
The Effectiveness of Rapidly Operated Slow Filters
Pre-Oxidation of Surface Water and Bank Infiltrate With a Mixture of Chlorine and Chlorine Dioxide
-Return of Treated Flume Water to the Raw Water
Elimination of Trace Organic Compounds by Infiltration of River Water Into Groundwater
-Horizontal Roughing Filtration as Pretreatment for Slow-Sand Filters in Developing Countries

UNITED KINGDOM Chertsey Automation Project
-Removal of Volatile Organics by Aeration
-Studies on Use of Ozone in Water Treatment

UNITED STATES Air Wheel Drive for Flocculation Equipment
-Ozone Pretreatment Effects on Biologically Activated Carbon, Disinfection and Treatment By-Products
Low Head Filter Backwash Design
Coagulant Control Test Apparatus
-TCE Removal From Groundwater Using Aeration in Smyrna, Delaware
Aquatic Plant Pilot and Bank Filtration Project, New Orleans, Louisiana
Pretreatment of Water Using Granular Activated Carbon
Effective Filtration Methods for Small Water Supplies
-Ultrafiltration of Surface Water for Color TOC and THMFP Reduction
Nutrient Film Technique for Wastewater Renovation
-Granular Activated Carbon as a Barrier Against Contamination
-Trident* Water Systems
-Ultra Sensitive Electronic Turbidimeters
-Automated Jar Testing System Optical Floc Testing by Microcomputer
-Closed-Loop Stripping Analysis for Determining Taste-and-Odor Causing Compounds
-Cost-Effective Optimization of Filtration Plant Performance Utilizing New Technology
Water Treatment With Activated Oxygen Photozone
Surface-Wash Systems for Filters Using the Baylis Nozzle
Radium Selective Complexer for Radium Removal From Potable Water
Ann Arbor Controls Trihalomethanes
Reduction of Total Trihalomethanes by Alternative Treatment Methods
-Hydroperm Cross Flow Microfiltration

WEST GERMANY Activated Carbon Adsorption for Removing Chlorinated Hydrocarbons From Groundwater
-Removal of Volatile Halogenated Hydrocarbons by Air Stripping and Activated Carbon Adsorption
-Energy-Input-Controlled Direct Filtration Wahnbach-System
-Specially Designed Approaches for the Production of Pure ClO_2-Solutions Using Chlorine
-Compact High Efficiency Flocculation Plant CFP
Production of Highly Purified Aqueous Calcium Hydroxide Solutions
-Powdered Carbon Filtration
-Refiltration Flocculation REFIFLOC Process
Upflow Filtration for Nitrification Denitrification and Iron and Manganese Removal
Treatment of Groundwaters Contaminated With Volatile Organic Substances
Macroreticular Ion Exchange and Biological Treatment of a Reduced Colored Groundwater
-Reinfiltration of Groundwater After Ozone Treatment and Oxygen Enrichment
-Aeration Using Corrugated Fiber Sheets
-Two-Stage Fluidized Bed Incinerator for Reactivation of GAC
-Advanced Wastewater Treatment for Groundwater Recharge
-"The Mulheim Process" for Treating River Waters Using Ozonation and Biological Treatment in GAC Filters

WATER QUALITY

CANADA Continuous Monitoring of Raw Water for Toxic Spills

FRANCE-Quantitative Analysis of Health-Related Organics at Low Concentration Levels
-Analysis of Organics and Their Mutagenic Activity in Drinking Water Treatment

ITALY-Monitoring Raw Water Quality Parameters

NETHERLANDS-Improvement of Water Quality During Storage in Reservoirs
-Automated Isolation and Sample Preparation for the Chemical and Toxicological Analysis of Organics

(continued on next page)

TABLE 2 - Continued

-Organic Halogen Determination OCl, OBr, and OI
-The Modified Fouling Index as a Measure of the Fouling Potential of Injection Well Water
-Detection and Evaluation of Mutagenic Activity in Drinking Water
-Easily Assimilable Organic Carbon (AOC) in Drinking Water

SPAIN-Localized Aeration as a Means to Break Reservoir Stratification Around an Intake Tower

SWITZERLAND-Continuous Monitoring of Several Quality Parameters of a River's Water
-Electronic System to Monitor the Effects of Drinking Water Pollution and Toxicity on Trout
-The Continuous Control of Quality Parameters During the Treatment Process of Drinking Water
-The Continuous Spectrophotometric Measurement of Chlorine Dioxide and Chlorite Using o-Tolidin
-The Utilization of Fish-Test Facilities for the Control of Water Quality

UNITED KINGDOM-Mutagenicity Testing Facilities
-Determination of Assimilable Organic Carbon in Water
-Rapid Detection of Bacteria in Water Using Impedance Measurement
-Microbial Tracing of Water Pollution
-Non-Volatile Organics in Drinking Water
-Biological Screening Tests for Toxicity

UNITED STATES-Isolation and Identification of Non-Coliform Bacterium From Potable Water
-Super Sensitive Luminescent Bacterial Bioassay for Assessing Toxicity in Potable Water
-Flavor-Profile Analysis of Drinking Water
-Immunofluorescence for Detection of *Giardia lamblia* Cysts in Drinking Water
-Rapid Bacteria Detection Instrument

DISTRIBUTION SYSTEMS

BELGIUM-Identification of Bacteria Which Cause Aftergrowth in Water Mains

CANADA-Evaluation of Alkalinity as a Predictor for Corrosive Activity

FRANCE-Optimal Control of a Large Water Supply Network: West Paris Case Study

NETHERLANDS-Conditions of Tap Water

NORWAY-Water Treatment for Corrosion Control Using Lime and Carbon Dioxide Gas
-Lime Dosing System for Corrosion Control Purposes

SPAIN-Quality Monitoring in the Distribution System: Feedback by Computerized Analysis

SWEDEN-Water Treatment for Corrosion Control Using Calcium Carbonate and Hydrochloric Acid

SWITZERLAND-REKA-Coupling for the Fiber-Cement Pressure Pipe
-Automatic Control of Large Water Distribution Networks With Decentralized Treatment Facilities
-Internal Refurbishment of a Large-Caliber Tamped Concrete Duct
-*Internal Refurbishment of Lead Sleeve Connections on Cast-Iron Pipes*
-Pressure Reliability in Drinking-Water Ducts

UNITED KINGDOM-Power Recovery in Water Distribution Systems
-Digital Recording of Water Mains and Associated Information

UNITED STATES-Realistic Replacement/Rehabilitation Criteria for Distribution System Components
-Flow Monitoring Utilizing Ultrasonic Techniques and Dye Injection
-Analysis of Water Main Breaks
-Retrofitting Small Hydroelectric Generating Plants Into an Existing Water Distribution System
-Hydraulic Simulation Model

WEST GERMANY-Use of a Fiberscope for Control Purposes in the Berlin Distribution System
-Special Cement-Mortar Lining of Ductile Cast-Iron Pipes

MISCELLANEOUS

CANADA-Micro-Computer Applications to Water Supply Technology

SWITZERLAND-Conception of an Emergency Water Supply
-Distribution and Storage of Drinking Water in Plastic Bags for Emergencies
-Protective Measures Against the Nuclear Destruction of Electrical Equipment by Electro-Magnetic Radiation

UNITED KINGDOM-Effects of Effluent Recharge on Groundwater Quality
-Simulation of Groundwater Quality, With Particular Reference to Nitrate

UNITED STATES-Hydrogenerating Units in Water Supply Systems

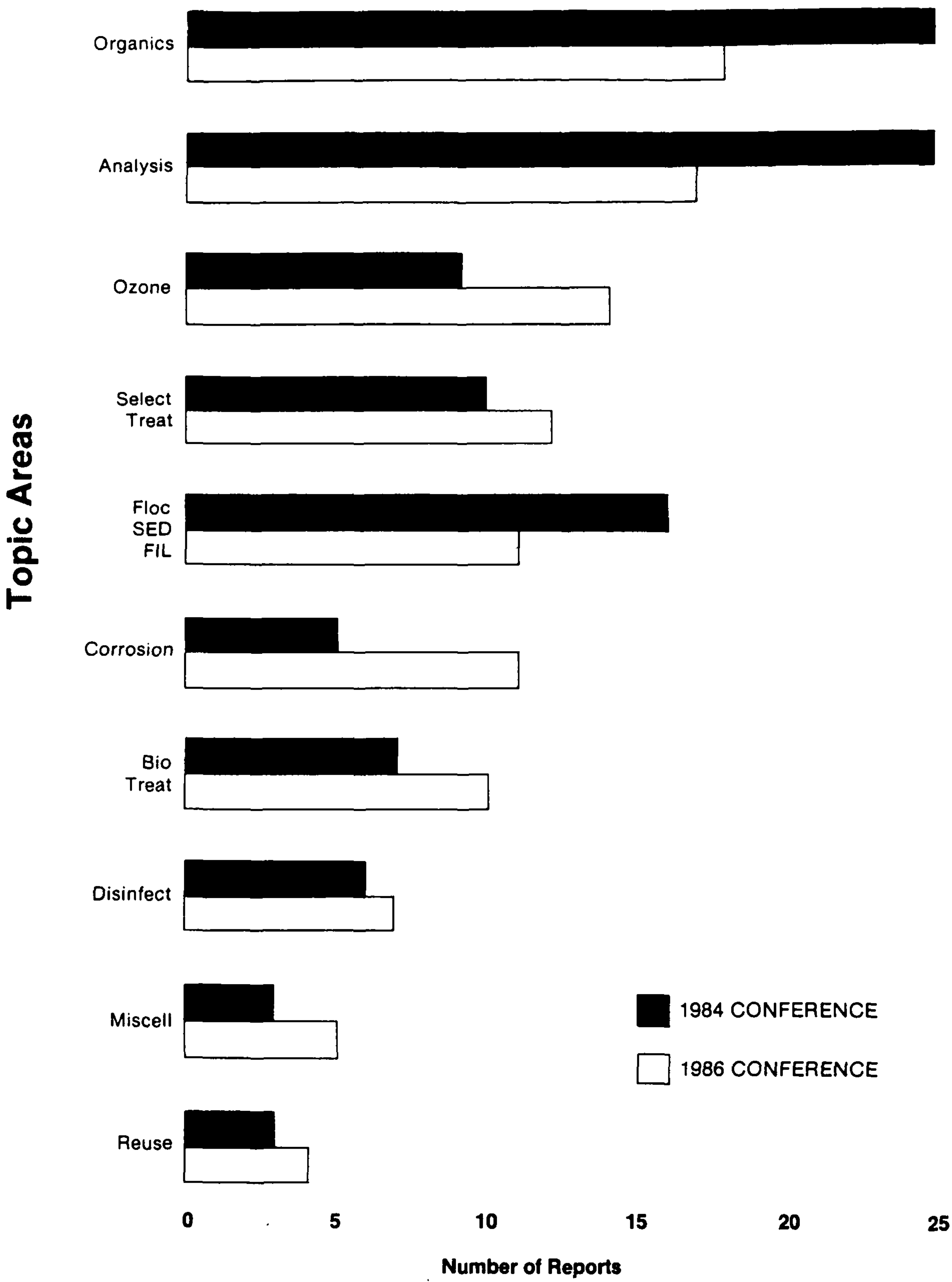

Fig. 1 Distribution of Research and Development Projects

POTABLE WATER TREATMENT TECHNIQUES TOWARD THE YEAR 2000

J. SIBONY & F. ROGALLA

Centre de Recherche du Groupe Générale des Eaux
Chemin de la Digue - B.P. 76
78600 Maisons Laffitte
(France)

ABSTRACT

Towards the year 2000 water will be treated in the majority of cases in plants built today and even yesterday.

The task ahead of research workers and engineers comprises three kinds of inventions:

- means of updating existing plants,
- flexible plants open to constant readaptation,
- radically new means of treatment.

A wide variety of successful examples of research are given:

- lamella clarification,
- ozonation and activated carbon filtration stages,
- biological processes.

Other subjects in the development phase are mentioned:

- treatment according to network water quality,
- combining ozonation and flotation for perfecting filtration and algae removal,
- improving disinfection with regard to flavour and undesirable by-products,
- sensors and expert-systems,
- biological applications and the use of fixed enzymes.

In order to benefit by the fallouts of research, a more dissociated concept of the different stages is necessary, with hydraulic profiles that allow flexible combinations.

Management of catchment areas or underground hydrographic systems will conserve and protect the water resources without hindering economic developments.

Centralising the management of several facilities allows to reduce expenses providing efficient services regardless of plant size and better emergency response.

Artificial intelligence research should obtain "self-stabilizing" methods avoiding sophisticated control processes and management installations.

Most of the progress mentioned is the logical continuation of the state of the art and hence incorporated into today's constructions.

Radically different techniques studied at present are described: new membranes, new adsorbant and disinfectant filtering media, genetic methods or pyrolysis of all the undesirable matter in water. Different scenarios, discussing the chances of practical implementation, are presented.

KEYWORDS

Adsorption; algae; biotechnology; filtration; future; improvement; membranes; modernization; modules; network; pyrolysis; research; sedimentation; sensors; ultrafiltration; upgrading; water treatment; year 2000.

RESEARCH OBJECTIVES

It must be remembered that in the vast majority of cases, water will be treated in the year 2000 on facilities built at the present time or even several years ago. These investments must give constant results and have to allow constant improvements. They are subject to maintenance and represent a considerable part of a country's assets.

To take an example close at hand, the Nice waterworks was built in 1972. The treatment line is to undergo certain alterations and the plant will continue to produce water of an excellent quality in the year 2000 (Fig. 1). There are countless such examples in France and most other industrialized countries (Fig. 1 & 2). In developing countries there are similar cases in the larger towns where waterworks will be updated or extended. In other cases an entirely new plant is required.

In view of this situation, the task of researchers and engineers can be divided into three parts:

1) finding means to modernize existing facilities to produce more and better quality water and in more reliable conditions;

2) designing today the plants likely to lend themselves easily to readaptation;

3) inventing new treatment methods applicable in all countries whether developed or not.

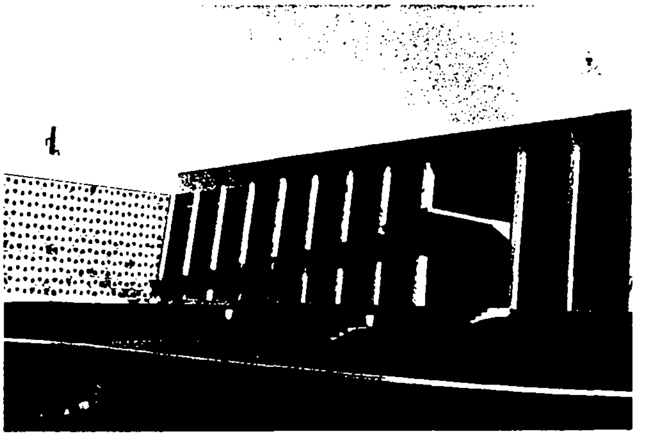

Fig. 1. In Nice (France), where ozone was first used as a water disinfectant, the Super Rimiez waterworks which will undergo some alterations will continue to produce water of an excellent quality (Doc. Compagnie Générale des Eaux)

Fig. 2. Aerial view of the Méry-sur-Oise water treatment plant, located near Paris, where ozone is injected at three points: first at the beginning of the treatment, ahead of the storage basin, then before and after activated carbon filtration (Doc. S.E.D.I.F.)

Fig. 3. At the Choisy-le-Roi plant (800,000 m^3/day) the treatment process was radically modified to make room for biological treatments and enhance the removal yield of organic matter. The synergies between the various treatment stages were closely studied. (Doc. S.E.D.I.F.)

FINDING MEANS OF MODERNIZING EXISTING PLANTS

Several new tools already exist and can be gradually incorporated in the various waterworks over the coming years. Let us begin by mentioning a few examples, working our way downstream along the treatment line from plant inlet.

Preliminary Suspended Solids Removal

Many waterworks in the Mediterranean and tropical regions are periodically clogged by the arrival of clay-type suspended solids at concentrations of 5, 10 or even 100 g/l, cutting production rates by half or even two-thirds. The construction of suspended solids removal facilities upstream restores their full capacity during such periods and also provides greater operating flexibility in normal times. The use of up-to-date techniques such as lamella clarifiers enables compact units to be incorporated in existing systems.

Algae Removal

This is another major problem encountered in industrialized countries and even more so in hot ones. The introduction of a flotation stage before clarification or instead of settlers can bring great improvements, since algae are easily floatable. To do this as simply as possible, we have designed, in addition to the known dissolved air flotation processes, a method specially targeted at algae (Bourbigot & coll., 1986; Bourbigot & Faivre, 1986). It consists of a simple bubbling process by adapted porous elements. The use of ozonated air for this flotation stage can considerably increase the removal efficiency and gives the extra-advantages associated with pre-ozonation.

Upgrading of Sedimentation Process

Several methods have been developed and applied to increase the flow rate of settling tanks and/or to improve the quality of the water produced:

* Complete revision of the flocculation system, helped by models, to reduce the reagent requirements by as much as 50%.

* Installation of lamellae enabling a double or triple flow rate on a settler (Fig. 4).

* Upgrading sludge removal systems by fitting scrapers to horizontal tanks where scraping was not provided (Dernaucourt, 1986)(Fig. 5).

* Injection and recirculation of micro-sand: current studies show that this addition to an existing settler can increase its flow rate 10 times!

* Convert a settling tank into a flotation tank.

Upgrading of Filtration

This includes the installation of finer filtering sand to improve the quality of the treated water, with a layer of lighter but coarser media on top to increase filtration cycle time and/or the production rate. This dual-layer filtration technique has been adapted for existing filters. By using activated granular carbon for the upper layer, a very advantageous treatment stage as regards water quality is gained without heavy investments (Bablon, Ventresque, Ben Aîm, 1987)(Fig. 6).

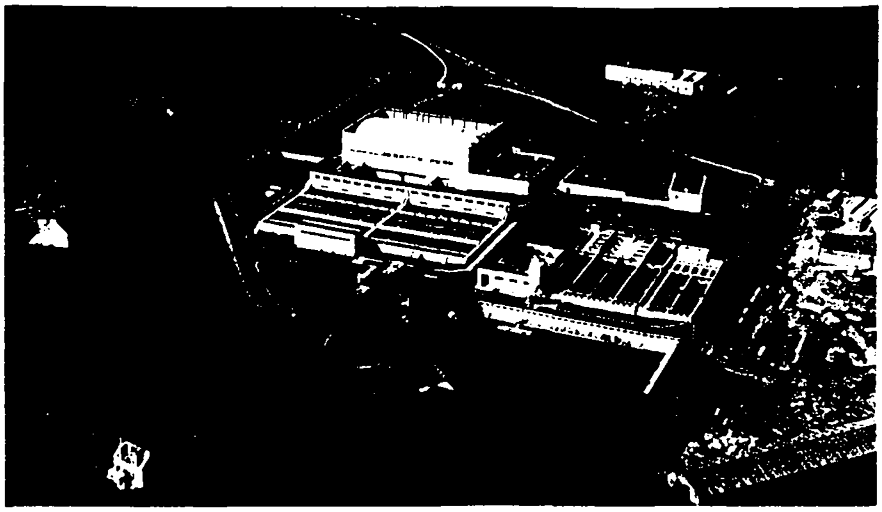

Fig. 4. Thanks to the installation of lamellae on the settling tanks of the Brest "Pont ar Bled" water treatment plant, the flow rate increased by 50% with a capacity going from 30,000 to 50,000 m^3/day while the quality of treated water improved (Doc. C.E.O.)

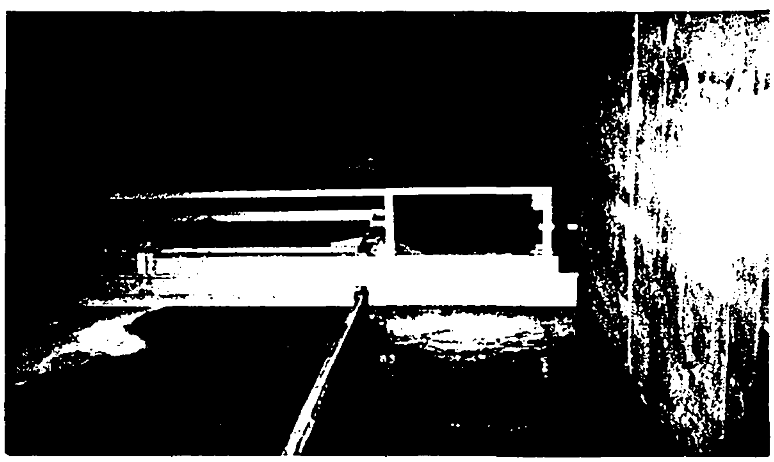

Fig. 5. The horizontal settling tanks of the Neuilly-sur-Marne water treatment plant have been fitted with scrapers upgrading sludge removal (Doc. S.E.D.I.F.).

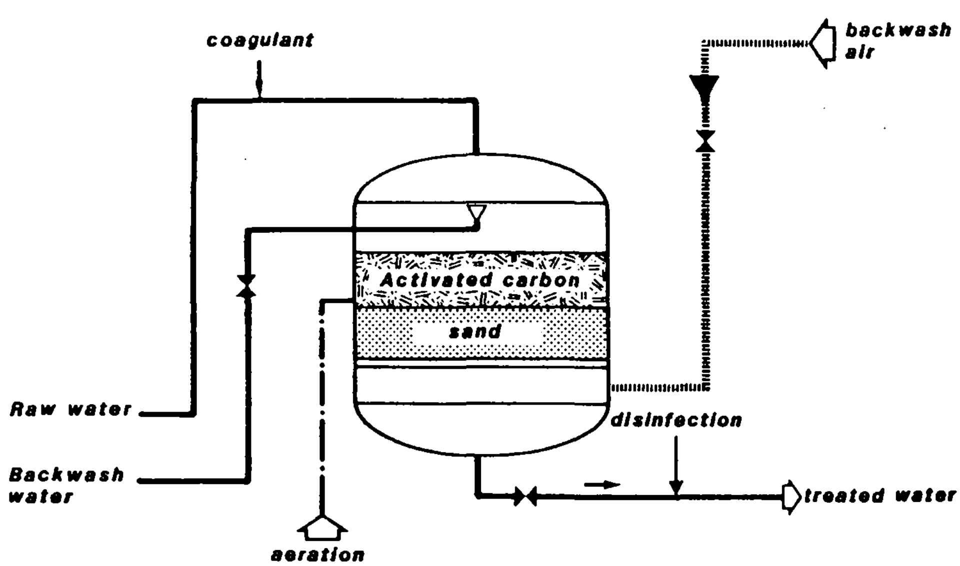

Fig. 6. Dual layer filtration with optional aeration

Shift from Chemical to Biological Methods

The treatment of ammonia (Houel & coll., 1982), iron and manganese (Boudou, Kaiser, Philipot, 1985) can, in certain conditions now fully understood, be incorporated in an existing facility.

In the case of ammonia, the treatment finds its place in existing filters after suppression of all prechlorination. The saving of a prechlorination reagent has the double advantage of substantially reducing undesirable organochlorine by-products. The conditions in which this treatment can be implemented are:

- presence or injection of a sufficient quantity of dissolved oxygen;

- sufficiently high pH and total alcalinity;

- temperature above 10°C at least during start-up;

- sufficient contact time downstream the filtration stage to enable transfer of chlorination;

In the case of iron and manganese the simplification achieved by biological treatment can bring additionally an increase of flow rate: filtration rates compatible with biological treatment are 5 or 6 times higher than those of physico-chemical methods.

These few examples show that the first task of water treatment operators in preparing the year 2000 is well advanced: we have just mentioned 10 or more examples of upgrading methods all developed and applied over the last 5 years. All are capable, in exchange for a few alterations, to allow existing plants to produce better quality water, often at an increased rate and a lesser cost.

DESIGNING MODERN PLANTS FOR CONSTANT READAPTATION

Modular Design and Data Processing

Most of the above-mentioned methods for upgrading existing plants are included, as adapted versions, in the construction of new facilities. The renovation of plants taught us various lessons. Of this experience we could gain valuable information and draw the following conclusions.

In the past there was a tendency to combine the different stages of treatment in a single, relatively inflexible structure. Today, we would be better advised to provide separate flocculation and sedimentation stages, a double filtration stage and a piezometric line that allows for the insertion of supplementary treatments.

It is also necessary from the outset to plan for methods that can be installed in stages: sedimentation can be designed immediately with a view to the future installation of lamella modules, capable of increasing production 3 or 4 times.

Automation of treatment stages must be planned now:

- to benefit from on-line information;

- to incorporate new treatment stages;

- to allow for and even anticipate the evolution of the raw water and quality standards.

Advanced techniques in computer sciences are particularly suitable for such objectives. They are defined by a number of complementary tools and characteristics:

- rule based systems where the updating of knowledge is very easy;

- a set of sensors or test results to feed the information base;

- a set of models to simulate each treatment stage;

- a choice of extremely "user friendly" terminals both simple and attractive, for use by unqualified operators.

This type of data-processing system makes full use of all the advances in Artificial Intelligence. The most efficient Expert-Systems are capable of proposing a choice of treatments and of explaining the reasons for such choice. The possibilities offered help to understand the capabilities and limitations of a facility, allowing its optimal use.

Easy simulation to forecasting future needs or the evolution of water quality and standards will reveal eventual bottle-necks long before they occur. Steps to avoid them can thus be taken in time based on the results of research in progress or studies initiated precisely in view of the forecast situations.

Advanced data processing is therefore an integral part of plants designed today as forerunners of facilities required at the beginning of the 21st century.

Treatment According to Networks and Retreatment in Networks

If the revamping of an existing plant, or even its replacement by new methods can be envisaged without excessive costs, the same does not always apply to networks. When assessing water quality, deterioration likely to occur in the network must be borne in mind.

Interest is already directed towards processes which decrease assimilable organic carbon in the treated water. An improved knowledge of network biology will enable us to direct treatment lines according to this objective.

In some cases the most effective and economical solution is to set up point of use treatment units upstream of particularly sensitives mains.

INVENTING NEW TREATMENT IMPROVEMENTS

With the idea of making optimum use of the money invested, we must distinguish means that can be incorporated in existing plants and those requiring radically new facilities.

The former would appear to come from two directions to which we should therefore give priority:

- adsorption
- biotechnology

Adsorption

At the present time none of the investigated new adsorbant media have proven to be more effective than activated carbon. Activated alumina shows interesting properties if we bear in mind its capacity to fix polarized and hydrophilic products. Acid or caustic regeneration produce polluted eluates that can be retreated and recirculated (Sibony, 1983; Chen, Leprince, Fiessinger, 1985). This method does not seem appealing to us because it goes against the rule of simplicity that governs the development of new processes. We continue research on new adsorption media. One attractive solution would be a media capable of retaining colloids and dissolved molecules once the coarser suspended solids have been removed. The benefit gained in the treatment line as a whole would then enable us to devote more effort to the treatment of a concentrated regeneration eluate and recirculate it indefinitely (Fig.7).

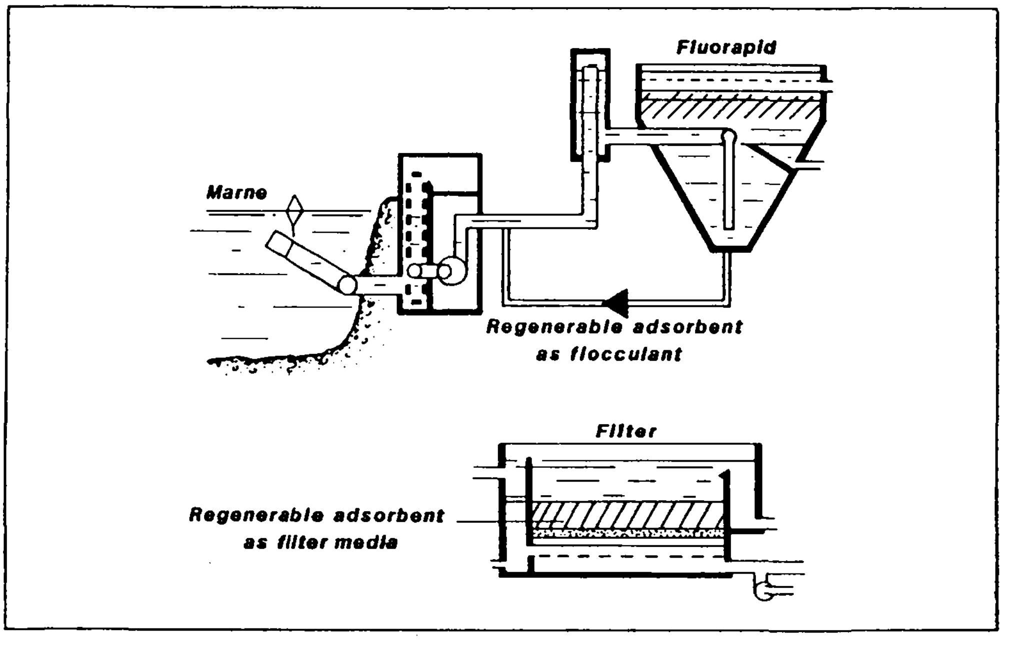

Fig.7 . The simplification achieved by biological treatment allow existing plants to produce better quality water often at an increased rate and a lesser cost: one attractive solution is a media capable of retaining colloids and dissolved molecules once the coarser suspended solids have been removed

Biotechnologies

These already exist, as is mentioned above, for the treatment of ammonia, iron and manganese and for assimilable organic carbon removal. We can add the treatment of nitrates (Philipot, Sibony, 1983; Philipot, Chaffange, Pascal, 1985) for which biology alone offers the possibility of total abatement. Current research is conducted in several directions:

- selection of strains liable to increase the efficiency of certain reactions directed at a particular pollutant;

- selection of media on which such strains will grow;

- research on the immobilisation of bacteria encapsulated in solid gels (Mishima, Watanabe, 1986);

- treatment by fixed enzymes. This seems to be the most logical method. Effective means of fixation and adequate fillers have been worked out (Klibanova & coll., 1982). Enzymes have been purified and have shown their efficacy in removing a number of specific micropollutants (Fiessinger & coll., 1984). Enzymes can be selected for their aptitude to catalyze a wide range of processes. We have been able to fix enzymes and operate their catalizing oxidation reactions in an open environment for periods up to several months (Chapsal & coll., 1986). Filtration tests resulted in the removal of a series of micropollutants including pesticides. Research currently in progress reveals additional possibilities offered by the same enzyme in the field of organic molecule dechlorination.

- the last possibility worth mentioning in this list of examples concerns mutation bacteria and ultimately genetic engineering. This area offers two perspectives:

. it will be possible to produce micro-organisms performing accelerated treatment. The efficiency of slow rate filtration will then be obtained on a greatly reduced surface. More compact units will be achieved by fixing micro-organisms throughout the depth of the filter;

. the second idea to be investigated is the production of micro-organisms secreting enzymes directly into the reactor eliminating all stages of enzyme purification and fixation (Fig.8).

As one might foresee. these new methods continue in the same direction as developments already initiated some years ago. In a treatment line including a filtering stage, nothing will prevent replacing natural seeding by introducing selected strains. Later on, one could replace the sand or activated carbon by a new material carrying fixed enzymes, encapsulated bacteria, or by an improved adsorbant medium that possesses the above mentioned properties.

In this concept. **sensors**, also using biotechnical resources (Fig. 9), will be widely applied for selecting the inclusion of a particular treatment stage along the flow path, the complete line being composed of industrialized elements assembled and used according to needs.

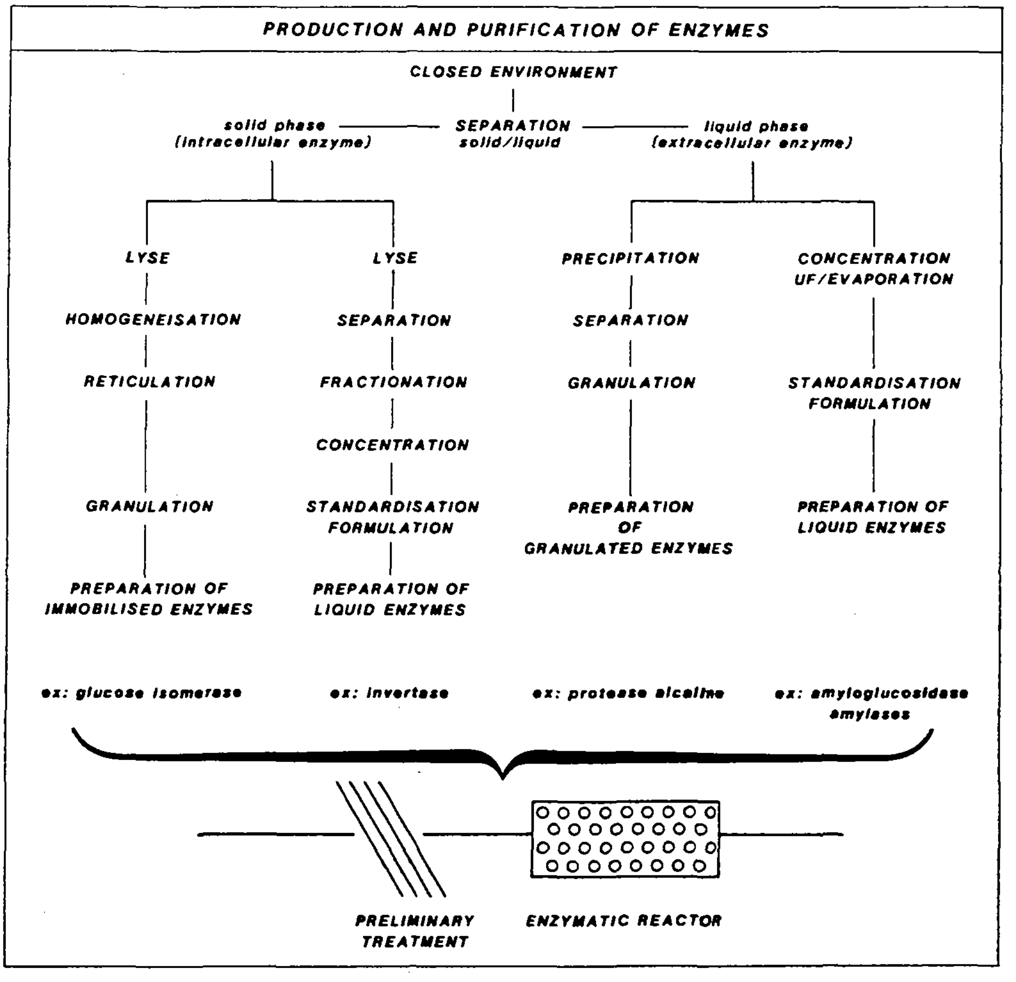

Fig. 8. In-line biocatalyst production and regeneration

In contrast to these methods that remain in line with existing processes, other **radically different means** should be mentioned, since they can open up new roads to applications in entirely redesigned facilities.

Membranes Processes

The first example using membranes for filtration, is already widely applied in the field of desalination. But what does the future hold for membranes in clarification treatments or the removal of micropollutants? In the first case, we already know how to replace traditional filters by micro-filtration cartridges when the water is free from colloidal particles. At the moment this process is economically competitive for small facilities. As energy consumption remains high, it is often restricted to seasonal application (Philipot & coll., 1986).

Before the field of application can be extended, progress in membrane design is needed to lower production cost coupled with reduced energy requirements.

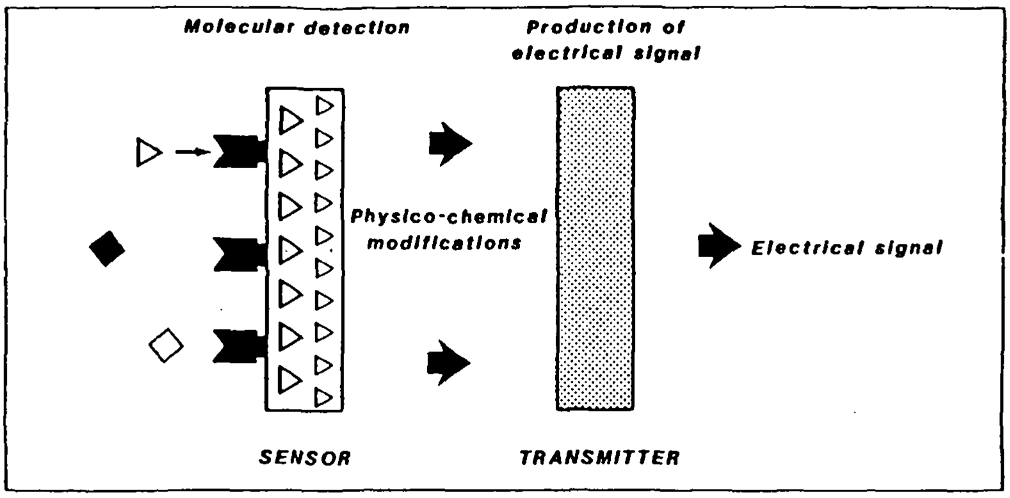

Fig. 9 . Example of enzymatic sensor

Pyrolysis

The action of powerful oxidizing agents can both completely destroy the organic content in the water and produce a mini-coagulation effect enabling the water produced to be put immediately through high-rate or membrane filters.

CONCLUSION

The above examples taken as a whole give an idea of the developments expected of water treatment techniques during the coming decades.

The existing structures will need some alteration in order to produce better quality water in greater amounts, and in safer, more stable conditions. Additional treatments will be incorporated upstream or downstream of existing stages.

The resources offered by biological techniques will be exploited in the aim of removing micropollutants detected by on-stream sensors or by alarm stations further upstream.

The different treatment stages will be activated according to raw water quality by computer-assisted selection, based on expert-systems capable of proposing the best combinations as a function of several criteria: required flow rate cost of production, temperature, estimated network residence time.

Productivity obligations will lead to the design of control centres covering several facilities. 80% of the action required being directed by expert-system assisted methods, qualified operators will intervene only in complex situations. This way, small waterworks will benefit from the same guarantees as the larger systems.

Certain facilities using totally different, unconventional methods will have been experimented. The results will tell whether the development scheme presented here has to be completely revised in favour of a plan that quickly induces the replacement of known techniques by radically new ones. Nobody can predict today the choice that will appear obvious tomorrow.

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CLOSING SESSION

SEANCE DE CLOTURE

- Transfer of Technology
  Transfert de technologie

by / par M.A. ACHESON (W.H.O - O.M.S.)

(Abstract - Résumé)

TRANSFER OF TECHNOLOGY

Abstract

The ways in which technology transfer in water supply and sanitation takes place have changed in recent years. These changes have been influenced by the International Drinking Water Supply and Sanitation Decade with its emphasis on the needs of unserved rural populations, the deficiencies of services in the urban slum and fringe areas, and the need for appropriate technology which will be accepted and can be operated and maintained by the users.

In the past, technology transfer involved the provision to developing countries of knowledge on advanced technologies for water supply and sanitation developed in industrialized countries. Many engineers and scientists from developing countries received their training and professional qualifications in universities in Europe and North America. The future trends will be towards increased development of technology adapted to the local conditions, resources and skills, and the use in developing countries of systems which can be operated relying more on available manpower than sophisticated equipment.

M.A. Acheson

POSTER PAPERS

TEXTES AFFICHES

AUTOMATISMES ET TELEGESTION

HORIZON 2000

Jean-Claude ARRAUDEAU

Compagnie Générale des Eaux - Anjou Recherche
52, Rue d'Anjou - 75384 PARIS CEDEX 08
(France)

MOTS-CLES

Technologies de pointe ; systèmes-experts ; innovation ; mini-ordinateurs ; micro-ordinateurs ; fibres optiques ; robots ; capteurs ; télégestion ; ultrasons ; eau 2000 ; France.

RESUME

Les automatismes et les systèmes de télégestion représentent la partie fonctionnant en temps réel de l'électronique et de l'informatique en usage dans les métiers de l'eau.

Leur mise en oeuvre fait appel à des techniques complémentaires mais sensiblement différentes comme les capteurs de mesure, les stations d'acquisition d'information et les automates, les techniques de transmission, les micros et mini-ordinateurs, les logiciels de traitement temps réel ou de gestion des données.

L'eau ne représente pour chacune d'elle qu'une très faible partie des applications pour lesquelles elles sont développées et nos métiers bénéficient donc des avancées technologiques effectuées pour les marchés les plus porteurs.

Les capteurs

Les capteurs de niveau, débit, pression utilisés couramment dans nos réseaux ont hérité des progrès de l'industrie dans le domaine notamment des jauges de contrainte (pression, niveau) des ultrasons ou des mesures électromagnétiques (niveau, débit).

Par contre, le domaine beaucoup plus spécifique à l'eau qui est celui des capteurs qualitatifs (chlore résiduel, oxygène dissous etc ...) ne bénéficie que peu de cette dynamique industrielle et demanderait de plus vastes efforts propres en recherche et développement.

Les systèmes d'acquisition et les automates

L'automatisation des processus industriels des vingt dernières années a permis la création de gammes d'automates très variés et performants dont nos métiers bénéficient aujourd'hui très largement.

Les techniques de transmission d'information

La fin du 20ème siècle se caractérisera sans doute par l'explosion de la télécommunication.

Là aussi nos exploitations bénéficient des spectaculaires progrès de ce domaine : techniques numériques de transmission, utilisation des réseaux téléphoniques, radio, télématique, arrivée des fibres optiques, etc ...

Cependant, il faut remarquer que certaines caractéristiques de nos besoins (fiabilité, stations isolées, conditions difficiles) font que l'adéquation entre ces besoins particuliers et les moyens existants n'est pas parfaite et restera sans doute le maillon le plus faible de la chaîne.

Les systèmes de traitement d'information

L'avènement de la micro-informatique a également bouleversé les façons de faire en télécontrôle de réseau d'eau et permet aujourd'hui de parler de "télégestion".

L'abaissement des prix des matériels et l'arrivée de moyens conviviaux : sorties graphiques, réseaux, écrans tactiles, etc ... permettent d'en envisager l'utilisation à tous les échelons d'un système.

C'est sur le développement de progiciels que nos efforts vont devoir maintenant se porter avec notamment l'utilisation des langages naturels, des systèmes-experts, des outils de modélisation dynamique permettant la création de logiciels spécifiques d'aide aux exploitants de réseaux d'eau ou d'assainissement.

Faire le point de l'état actuel et surtout prévoir l'évolution des treize prochaines années n'est certes pas chose facile compte-tenu des avancées très rapides de ces techniques.

Malgré tout, quelques lignes directrices peuvent être dégagées qui soulignent les efforts qui seront demandés à nos domaines propres de recherche et développement.

AUTOMATONS AND TELEMANAGEMENT

HORIZON 2000

Jean-Claude ARRAUDEAU

Compagnie Générale des Eaux - Anjou Recherche
52, Rue d'Anjou - 75008 PARIS
(France)

KEYWORDS

Advanced technologies ; expert systems ; innovation ; microcomputers ; minicomputers ; optic fibres ; robots ; sensors ; tele-management ; ultrasonics ; year 2000.

ABSTRACT

Automatons and telemanagement systems represent the real time activity of the electronic elements and data processing as applied to the water profession.

Their installation requires the use of additional instrumentation, both complementary and different such as metering sensors, data collection units and robots, transmission techniques, mini and microcomputers, as well as real time treatment or data management software.

Water treatment accounts for only a very small part of the applications for which they are designed and so our different crafts benefit from the fallouts of advanced technologies devised for sale on a much wider market.

Sensors

The level, flow-rate and pressure sensors extensively used in our networks have been inherited from the progress made in other fields, particularly stress gauges (pressure, level), ultrasonic or electromagnetic metering instruments (level, flow-rate).

On the other hand, the material more specifically designed for the water facilities, such as quality sensors (residual, chlorine, dissolved oxygen control, etc.) is not swept up in the dynamics of the industry as a whole and so a much greater personal research and development effort is necessary.

Data collection and automatons

The automation of industrial processes over the last 20 years has given birth to a wide variety of highly efficient robots that are now of great use to our own industry.

Data transmission techniques

The end of the 20th century will no doubt be characterized by a telecommunications explosion.

In this field also our facilities will get the benefit of the spectacular progress made : digital transmission techniques, telephone links, radio, remote processing, optic fibres, etc.

It is to be remarked, however, that certain aspects of our needs, like reliability, isolated works, difficult conditions, are such that the means already developed are not perfectly adequate to our requirements and will remain still one of the weaker links in the chain.

Data processing systems

The arrival of micro-processing has also revolutionized methods of telecontrol in water network, that today can be more suitably described as tele-management.

Cheaper equipment and the appearance of compatible peripherals such as graphic printout, networks, tactile screens, etc, open the prospect of applications at all levels of a system.

In the immediate future, we must above all direct our efforts to the elaboration of software packages, including the use of natural language, expert systems, dynamic modeling devices, with which to achieve specific software to assist operators of water and sewage works.

It is certainly no easy matter to make a survey of the present state of the art or forecast developments within the next 13 years.

It is nevertheless possible to recognize the general trends and definitively emphasize the need for effort in our special sphere with regard to research and development.

A FLOC MONITORING SYSTEM WITH IMAGE PROCESSING FOR WATER PURIFICATION PLANTS

Kenji Baba*, Mikio Yoda*, Hiroyuki Ichiki** and
Asao Osumi***

*: Hitachi Ltd, Hitachi City, Ibaraki, Japan
**: Kurume Water Spread Authority, Kurume City, Fukuoka, Japan
***: Osaka Water Works Bureau, Osaka, Japan

ABSTRACT

A floc monitoring system, which enables monitoring of floc formation characteristics continuously and quantitatively, was developed. In this system, images of flocs in flocculation basins are processed on line by a high speed image processor. The floc size distribution was calculated in 5-20 min based on 2,000 to 10,000 flocs. Experiments conducted in full scale water purification plants, elucidated the fundamental aspects of floc formation process. The system should offer a means for monitoring and controlling flocculation-sedimentation processes for sophisticated administration of water purification and wastewater treatment plants.

KEYWORDS

Floc; Flocculation; Sedimentation; Image processing; Monitoring; Control; Coagulant

INTRODUCTION

Flocculation-sedimentation processes are found as the principal operation unit for a water purification plant. While many researchers have studied mechanisms of the flocculation process on a laboratory scale, the nature of flocculation in a full scale plant is not well understood. So, in practice, jar tests in the laboratory or turbidity measurements in a sedimentation basin are widely used by plant operators. However, these cannot be used for controlling the flocculation or sedimentation process without time lag. Then the most reliable method in practice is a visual monitoring of flocs. But, the reliability is low because it is subjective and intermittent monitoring.
In this paper, a new monitoring system, in which floc formation characteristics were measured continuously and objectively on line, was developed using image processing techniques.

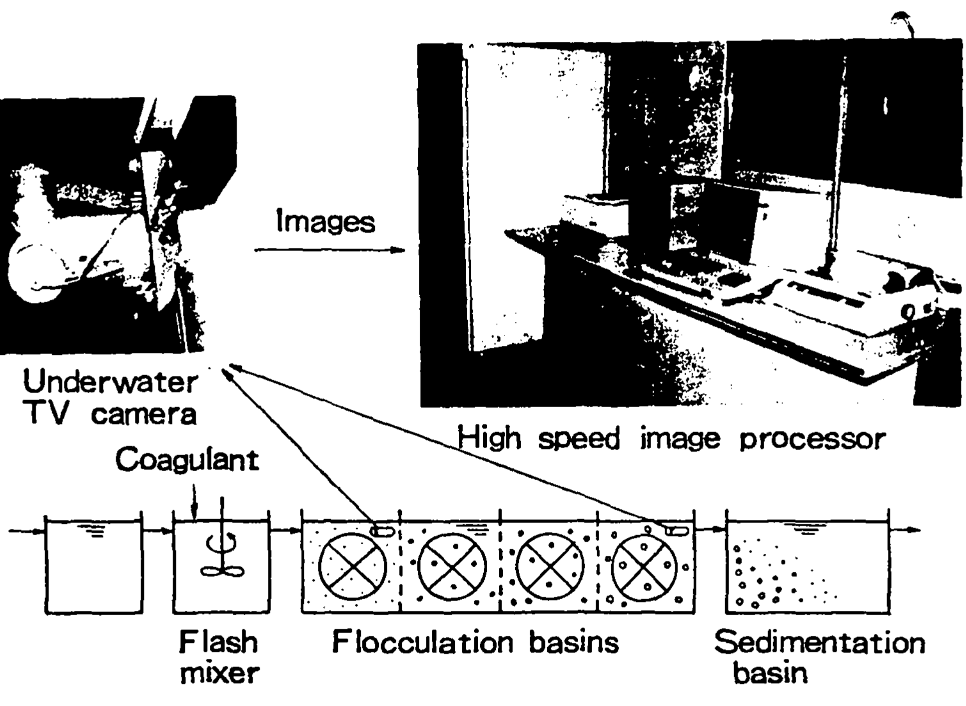

Fig. 1 System configuration

SYSTEM CONFIGURATION

The system configuration is shown in Fig. 1. The system contain an underwater television camera for flocs and a high speed image processing machine.
The television camera gets pictures of mixed liquor (H:40-52 W:40-52 D:15-16) which contains a number of flocs illuminated. Analog signals obtained by the television camera are transported to the image processor.

FLOC IMAGE ANALYSIS

A block diagram for image monitoring is shown in Fig. 2.
The image signals of flocs are converted to digital signals in memory. An example of floc images got by the system is shown in Fig. 3.
The optical brightness intensity in the A-area of Fig. 3 is illustrated in Fig. 4, where each mountain indicates floc (Ichiki, 1987a). Each floc is recognized in less than 0.3 s and then binarized as shown in Fig. 5. In the next step, the floc volumes are calculated under the assumption that they are spherical. After that, the floc size distribution is calculated at statisticaly reliable level in 5 to 20 min based on 2,000-10,000 flocs in 10-15 images.

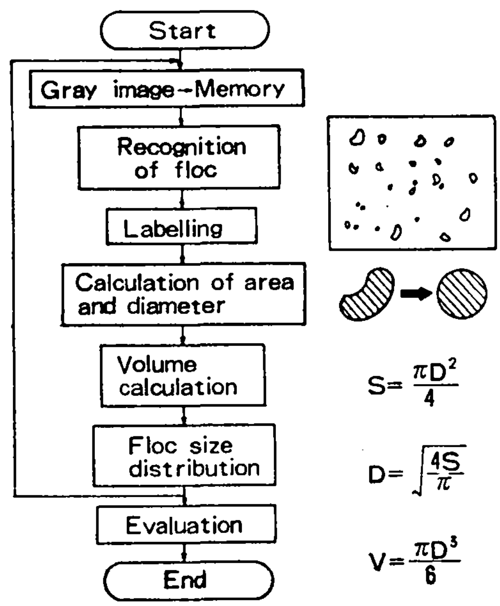

Fig. 2 Block diagram for floc image monitoring

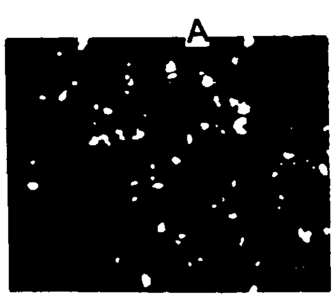

Fig. 3 Gray image of flocs (Araki Plant)

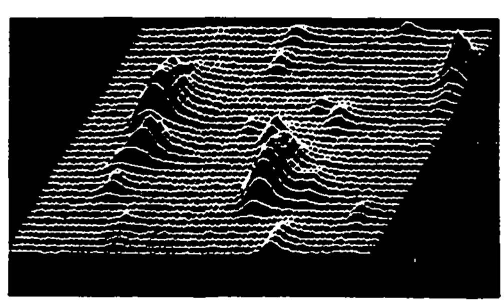

Fig. 4 Optical intensity distribution of flocs

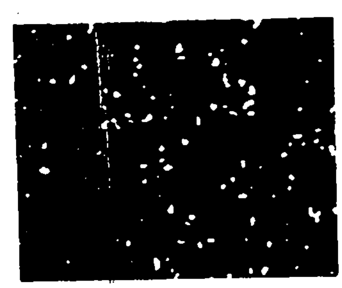

Fig. 5 Binary image of flocs

TABLE 1 Flocculation System of Full Scale Plants

Full scale plants	Number of flocculation basins	Coagulant
Kurume Water spread Authority Araki Water Purification Plant	Three	PAC Poly-Aluminum chloride
Osaka Water Works Bureau Oba Water Purification Plant	Four	Al_2SO_4

FULL SCALE INVESTIGATIONS

The developed system was applied to full scale plants (Table 1).
The following results were demonstrated quantitatively in a series of floc image monitoring investigations (Ichiki, 1987a, 1987b, Baba, 1987).

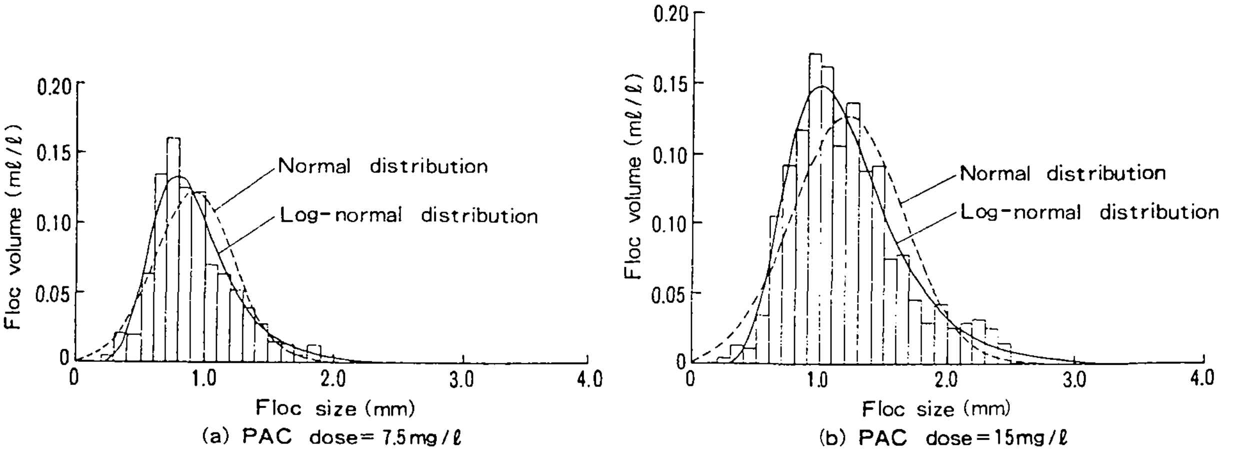

Fig. 6 Suitability of statistical distributions for floc volume distributions (Araki Plant)

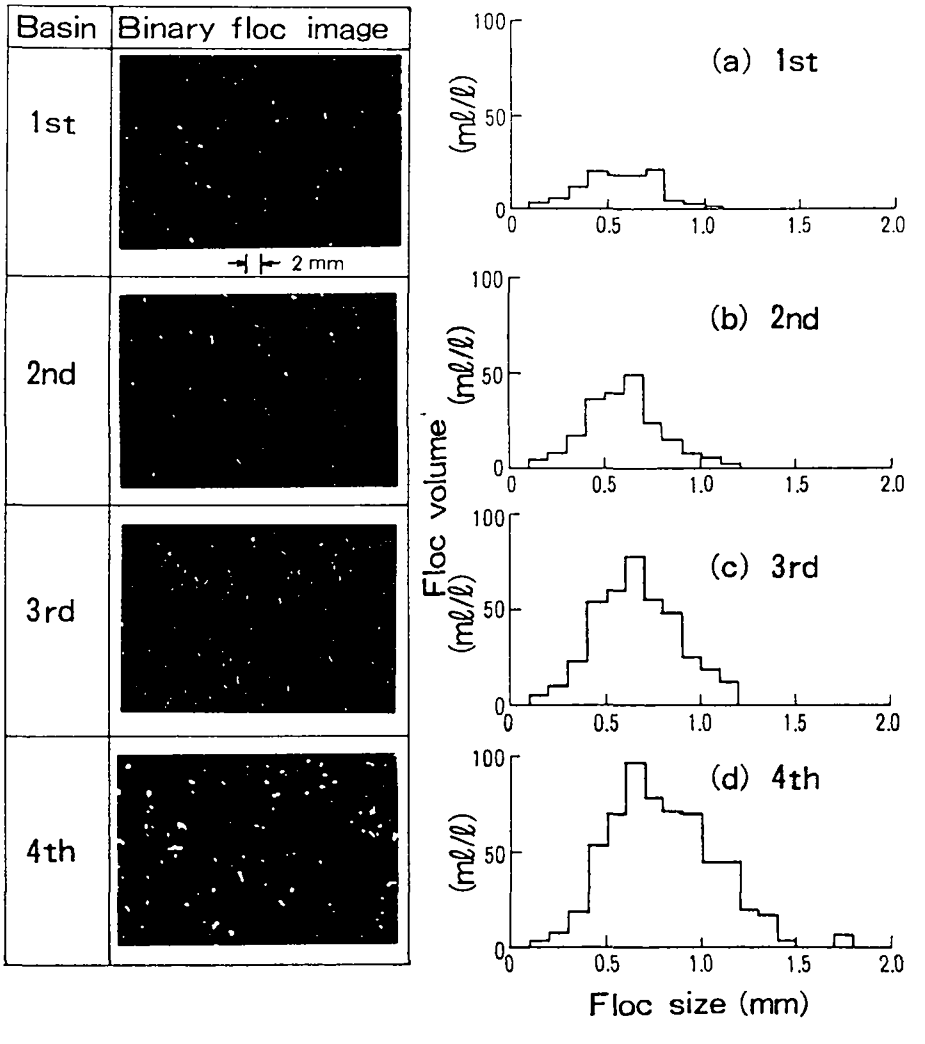

Fig. 7 Floc formation characteristics along flocculation basins (Oba Plant)

FUNDAMENTAL CHARACTERISTICS OF FLOC FORMATION PROCESS

Fig. 6 illustrates that the suitability of statistical distributions for floc volume distributions in the third basin under different coagulant dose conditions. The floc volume distribution can be represented as a log-normal distribution, based on the validities for normal and log-normal distributions using t-test.
Fig. 7 demonstrates that the floc image nomitoring system is effective for quantifying floc formation conditions in the full scale plant. Conditions under which the floc grew in the first to fourth flocculation basins are shown there.
The geometric mean diameters (GMD) in these basins is calculated from the data plotted. In this paper, the GMD is applied to evaluate the degree of floc formation , because floc volumes change depending on turbidity and other conditions. The GMD, which represents average floc size as got by visual observation, increases from the first to fourth flocculation basins as shown in Fig. 8.

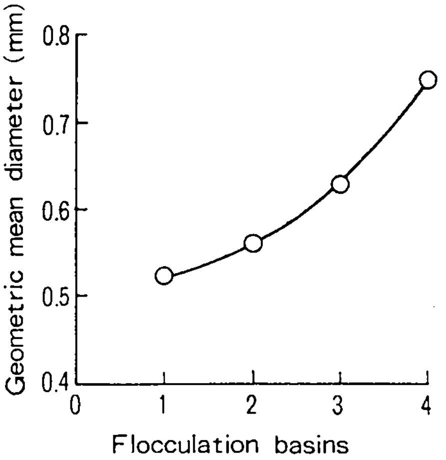

Fig. 8 Change in geometric mean diameters along flocculation basins (Oba Plant)

INFLUENCES OF COAGULANT DOSE AS A CONTROL MEANS

Influences of coagulant dose, which is a major control means, on floc formation characteristics were investigated. Based on a series of experiments, which were carried out under nearly the same conditions, Fig. 9 could be obtained. That is, the values of the GMD in the third basin increase and values of log-standard geometric deviation are nearly equal for increased coagulant doses.
Furthermore, the quality (Tambo, 1979a) of flocs formed was examined in the same experiments. The average effective density of floc was defined as the suspended solids (mg) divided by the total floc volume (ml) calculated on the basis of recognized floc images. As shown in Fig. 10, the average effective density decreases corresponding to the increased PAC dose. Therefore, turbidity in the sedimentation basin outlet increases as shown in Fig. 11 when much more coagulant is injected. These results suggest that exess coagulant is not effective for floc clarification.

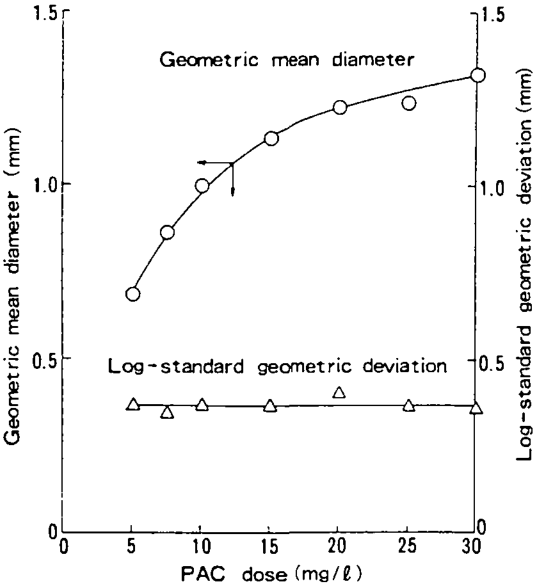

Fig. 9 Influences of coagulant dose on statistical characteristics of floc size distribution (Araki Plant)

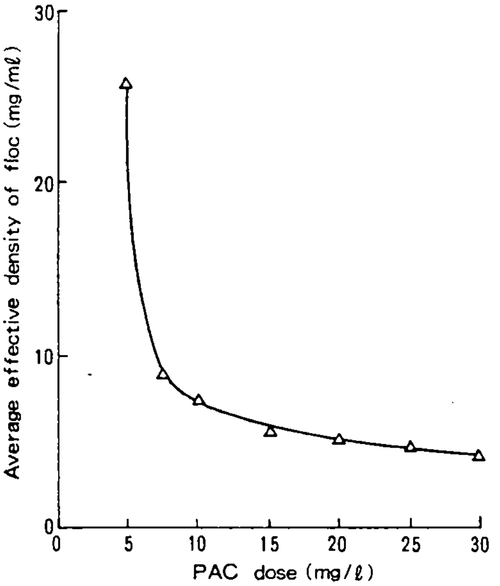

Fig. 10 Influences of coagulant dose on average effective density of floc (Araki Plant)

PRACTICAL EFFECT OF THE FLOC MONITORING ON COAGULANT CONSUMPTION

A continuous floc monitoring experiment (Fig. 12) in which the coagulant dose was kept at 30% lower than the usual level was carried out (Baba, 1987).
GMD in the first baisn was selected for monitoring of floc formation beforehand. On the other hand, GMDs in the fourth and first basins were measured to confirm floc formation. During the experiment, GMDs in the first basin were kept at 0.55-0.60 mm. The results of Fig. 12 show that conserving coagulant is possible when floc image monitoring offers an assurance of floc formation in the first basin. So, the system is expected to serve as a possible means of reducing the coagulant consumption rate.

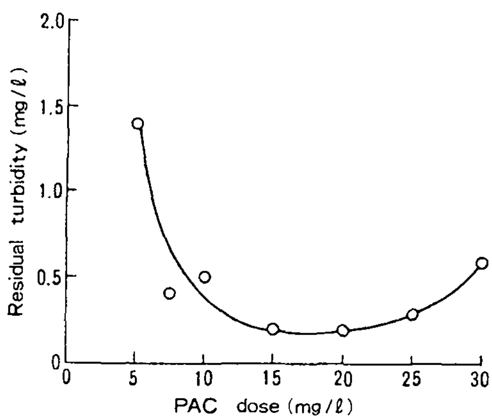

Fig. 11 Influences of coagulant dose on turbidities in sedimentation basin outlet (Araki Plant)

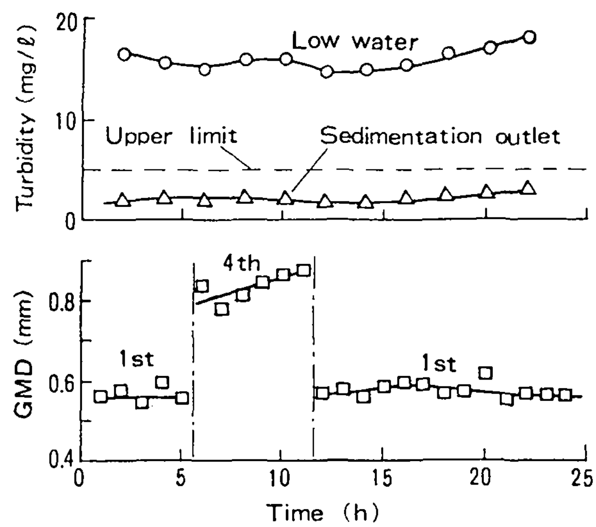

Fig. 12 Flocculation-sedimentation effect during a controlled experiment (Oba Plant)

CONCLUSIONS

Results obtained in this paper are summarized below.

1) Floc volume distribution could be represented as a log-normal distribution according to the t-test.
2) The values of the geometric mean diameter increased and values of log-standard geometric deviation were nearly constant for increased coagulant doses.
3) Average effective densities of the flocs decreased and residual suspended solids in the sedimentation basin increased for increased coagulant doses.
4) The proposed system should serve as a means to lower the coagulant consumption rate.

The proposed system should offer a good way of monitoring and controlling the flocculation-sedimentation process in laboratory investigations as well as providing sophisticated administration of water purification or wastewater treatment plants.

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INTRODUCTION DE L'INFORMATIQUE GRAPHIQUE DANS DES ENTREPRISES DE DISTRIBUTION D'EAU

F. BARRACHINA et J. COLL

SOCIEDAD GENERAL DE AGUAS DE BARCELONA, S.A.

ABSTRACT

L'objectif de cette étude est de déterminer la viabilité et l'opportunité d'introduire l'informatique graphique dans des entreprises de distribution d'eau et d'estimer son impact dans l'organisation. La méthodologie suivie est la suivante: i) analyse du système d'information graphique actuel et estimation de son évolution, ii) standardisation des besoins graphiques, iii) dessin de système d'information mécanisé, essais pilote et planification de son implantation, iv) analyse d'opportunité coût/bénéfice. Le résultat de l'étude nous indique deux champs de mécanisation clairement délimités: i) unités de délinéament, ii) système d'information sur le réseau de distribution. Celui indiqué en premier lieu ne présente aucune difficulté technique ni économique, alors que le deuxième champ suppose un important effort économique et technique/d'organisation, en outre une partie de son opportunité économique se matérialise dans des bénéfices intangibles, dont le principal est l'amélioration qualitative du système d'information du réseau de distribution. Cette communication quantifie et évalue les aspects signalés.

KEYWORDS

Système d'information, réseau de distribution, mécanisation graphique, opportunité économique, standardisation de besoins graphiques, cartographie, activités de délinéation.

L'INFORMATION GRAPHIQUE DANS DES ENTREPRISES DE DISTRIBUTION D'EAU

Système d'information graphique

Les éléments graphiques habituels dans une entreprise de distribution d'eau peuvent se classer fonctionnellement comme suit:

1. Système d'information graphique du réseau, SIGR. Plans de cartographie du réseau, plans de project et plans de localisation de singularités; utilisés pour résoudre les avaries, dans la mise en oeuvre de nouveaux approvisionnements et dans les travaux d'agrandissement, de modification et de renforcement du réseau.

2. Système d'information graphique des installations d'exploitation, SIGIE. Plans de schémas électriques, mécaniques et de travail civil des installations; utilisés dans le maintien et le projet d'installations dans le champ technique de l'entreprise comme documentation technique et légale.

3. Système d'information graphique de propriétés et bâtiments, SIGPYE. Plans de propriétés et terrains; utilisés dans le maintien, la conservation et le projet des édifices de l'entreprise, ainsi que pour la délimitation de son patrimoine.

4. Ensemble d'information graphique de projets singuliers, IGPS. Il contient des plans de projet et de liquidation intégrés par des fondements, des profils et des détails de conduites, utilisés comme information technique et légale dans le développement de projets ayant une envergure spéciale.

5. Ensemble d'information graphique de l'environnement, IGE. Il contient des plans généraux et de détails des zones d'influence de l'entreprise; cartographie des bassins hydrographiques utilisée soit pour localiser des points d'intérêt dans des conflits avec des tiers sur le captage et les versements d'eau ou pour donner une vision globale des bassins hydrographiques des sources d'approvisionnement.

6. Ensemble d'information d'origine alphanumérique, IOA. Utilisé comme représentation graphique résumée des résultats de gestion et pour des représentations graphiques en général, (tableaux, diagrammes, graphiques).

Standardisation de besoins graphiques

Ces ensembles d'information présentent des besoins graphiques qui conceptuellement se normalisent sous trois formes:

Type-1: Besoin d'un outil de dessin.

Type-2: Besoin d'un système d'information appuyé sur un dessin schématique.

Type-3: Besoin d'un système d'information appuyé sur une cartographie de base.

Le premier représente le besoin de production et traitement d'information graphique. Il s'agit d'une mécanisation opérative dont l'apport sera une réduction dans la charge de travail et une plus grande rapidité d'action.

Les besoins type 2 et 3 incluent ce besoin et demandent la structuration de systèmes d'information de nature graphique, avec les missions propres de système d'information:

- Capter les renseignements qui jour par jour se produisent sur la réalité représentée.

- Structurer et enregistrer ces renseignements.

- Les préparer pour la consultation des personnes et des unités de l'entreprise et de son environnement.

Chacun des systèmes ou ensembles d'information ci-dessus mentionnés présente un besoin standard déterminé. Le SIGR de type 3, qui suppose la mécanisation d'un système informatique clé pour l'entreprise. Le SIGIE et le SIGFYE de type 2 et l'IGPS, l'IGE, l'IOA type 1.

Espaces de mécanisation

Les systèmes d'information type 2 intègrent de l'information passive, avec un niveau faible de consultation ce qui fait que généralement on n'envisage pas leur mécanisation.

Les deux autres demandent des systèmes mécanisés qualitativement différents, tant sous leurs aspects techniques comme d'organisation, ce qui fait qu'on considère la mécanisation de chacun d'eux séparément.

MECANISATION DES ACTIVITES DE DELINEATION

Mécanisation proposée

Le besoin de type 1 se localise dans les unités de délineation de l'entreprise. La proposition de mécanisation consiste en les douer d'un système qui mette en évidence leurs capacités de travail et projection, en permettant les spécifications fonctionnelles suivantes:

- Leur utilisation comme outil en remplacement des moyens employés actuellement.

- Leur utilisation comme application graphique fermée pour la génération automatique de plans standardisables et répétitifs.

En même temps elle se propose d'étudier la viabilité de mécanisation des archives de plans au moyen de la digitalisation avec scanner et classement sur disques laser, qui permette:

- La consultation par écran de l'archive général de plans sur disques laser.

- Catalogue général et système de consultation de l'archive de plans.

Coûts

On propose un réseau local de PC's doués d'un écran graphique de haute résolution, avec une table digitalisatrice et un paquet de logiciel de dessin en deux dimensions. Le coût d'un réseau avec trois stations graphiques et un traceur, est de 12 millions de pesetas environ. Le coût du système de classement sur des disques laser et du développement de software de visualisation nécessaire s'évalue en 14 millions de pesetas.

Délai de développement

Le délai d'implantation du système de dessin est de six mois environ. On estime que le délai d'implantation du système de disques laser est de 12 mois, à partir de ce moment-là on pourra commencer l'introduction de plans dans le système.

Bénéfices

L'implantation du système mécanisé de dessin suppose:

- Une réduction dans la charge de travail de 30%, qui permet l'amortissement du système en quatre ans.

- Introduction douce de l'information graphique dans l'entreprise, en rendant plus facile l'introduction postérieure d'un système d'information sur le réseau avec un apport d'expérience pour le département d'informatique et les unités utilisatrices.

- Temps de réponse plus rapides des unités de délinéation devant des demandes de services qui leur sont faites, et accommodation des professionnels du dessin aux nouvelles techniques, car le dessin technique dans sa réalisation classique est en train de devenir obsolète.

Les principaux bénéfices de la mécanisation de l'archive général de plans sont:

- La conservation de ceux-ci, étant donné que la consultation physique de l'archive de façon constante abîme les originaux.

- La facilité d'accès aux plans, du fait de l'augmentation du nombre de clés d'accès et la rapidité de consultation.

MECANISATION DU SYSTEME D'INFORMATION GRAPHIQUE DU RESEAU

Mécanisation proposée

Pour le besoin de type 3 la proposition de mécanisation consiste à développer un système mécanisé d'information graphique interactif, qui permettrait:

- La réalisation des fonctions propres comme système d'information de consultation et actualisation d'une base de renseignements graphique sur le réseau de distribution, à partir des unités chargées de leur exploitation journalière.

- L'utilisation comme outil de travail pour l'établissement de plans de projet, de permis et la réalisation de statistiques.

- La structuration en base de données d'information alphanumérique associée au réseau de distribution, pour la consultation et l'élaboration de statistiques.

- Rendre plus facile l'échange d'information graphique sur le réseau, avec les organismes officiels et d'autres entreprises de services.

Coûts

On propose un système graphique interactif structuré autour d'un Centre de Procès Graphique avec des stations graphiques de travail dans les unités usagères.

- La structuration du Centre de Procès Graphique suppose la création d'une unité avec du personnel informatique spécialisé dans le domaine de l'informatique graphique, (environ quatre personnes), avec un coût annuel d'exploitation.

- Le coût de l'équipe hardware et software pour cette unité est d'environ 50 millions de pesetas.

- Le coût de chaque station graphique dans les unités usagères est de plus ou moins 10 millions de pesetas.

- Le coût de développement software est estimé en 20 millions de pesetas.

- Le coût de la cartographie de base avec support magnétique, pour la zone comme celle de Barcelone est de 15 millions de pesetas.

- Le coût de la digitalisation du réseau de distribution sur la cartographie de base est estimé en 13 millions de pesetas, pour une zone comme celle de Barcelone.

-Finalement, l'introduction dans la base de données d'information alphanumérique associée au réseau peut supposer 4 millions de pesetas.

Délai de développement

Pour le développement et l'implantation total du système on prévoit un délai de 2 ans, le système entrant dans sa pleine explotation au bout de 2 ans et demi.

Bénéfices

Cette mécanisation suppose:

- Le résultat principal de la mécanisation est une amélioration qualitative de l'information sur le réseau de distribution avec un potentiel d'améliorations dans la gestion de celui-ci.

- En outre, une réduction dans la charge de travail de production graphique.

Pour la SGAB, les bénéfices que cela suppose sont estimés à 75% du coût de la mécanisation, le 25% restant étant le coût stratégique de l'action de mécanisation.

CONCLUSIONS

La synthèse de notre expérience dans la mécanisation de l'information du réseau de distribution nous montre que:

- La mécanisation du système d'information graphique d'un réseau de services est une action stratégique de bénéfices à long terme, en rapport avec l'amélioration de la gestion et la connaissance du réseau de distribution, c'est-à-dire avec une amélioration qualitative de l'information.

- La mécanisation apporte une augmentation nette de la charge de travail global de l'entreprise, avec une spécialisation des postes de travail.

- L'information d'un réseau de distribution est intégrée principalement par des informations de nature alphanumérique, les informations graphiques étant une simple aide à la localisation relative des éléments formant le réseau.

- Les systèmes graphiques actuels spécialisés du marché, étant donné qu'ils sont principalement orientés vers le traitement d'information graphique, ne fournissent pas des prestations suffisantes quant à la gestion de l'information alphanumérique associée au graphisme.

- Les systèmes graphiques de l'avenir n'auront rien à voir technologiquement avec ceux actuels, mais l'information accumulée et structurée et l'expérience de fonctionnement acquise constituent des valeurs permanentes qui pourront être utiles à l'entreprise en favorisant l'utilisation optimum de la technologie disponible à chaque moment.

- Il est d'une grande importance de disposer d'une cartographie de base créée et actualisée par des organismes externes à l'entreprise.

Notre expérience dans la mécanisation des activités de délinéation de l'entreprise nous montre que:

- La mécanisation des unités de délinéation constitue une action opérative, de bénéfices tangibles à court terme.

- Elle constitue une base pour le développement et l'implantation de systèmes graphiques plus complexes, ce qui fait qu'il convienne de la réaliser le plus tôt possible.

- Elle suppose une réduction dans la charge de travail.

- L'apprentissage ne présente pas des difficultés conceptuelles pour les professionnels du dessin.

- Pour les dessinateurs, les systèmes de dessin en deux dimensions accelèrent la capacité de préfiguration dans le procès de dessin et la capacité d'exécution dans la production graphique, la conception du dessin ne variant pas. Cela a representé une expérience congratulante pour les usagers du système, qui craignaient que la mécanisation ne suppose une perte de créativité dans leur travail.

- Les PC's et les paquets "clés à la main" de dessin en deux dimensions, couvrent largement les besoins des activités de délinéation.

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GESTION OPTIMALISEE DE RESAUX DE DISTIBUTION D'EAU : METHODE ET PHILOSOPHIE.

Ir. A. FLEMAL *, Pr. Ir. A. BLAVE **, Pr. Ir. J. TRECAT **

* APPARELEC, Montignies/S/Sambre - Belgium

** FACULTE POLYTECHNIQUE DE MONS - Belgium.

ABSTRACT

Survol de la méthode utilisée pour optimaliser un réseau de distribution d'eau d'une grande ville, basée sur un système d'acquisition de données en temps réel et sur une gestion sur micro-ordinateur.

KEYWORDS

Optimalisation, réseau de distribution, automatisation, simulation, sécurité de transmission, télégestion.

INTRODUCTION

Afin de rationaliser les réseaux de distribution d'eau, les coûts énergétiques de pompage et les coûts de personnel doivent être réduits. Cela implique la création et l'utilisation d'une gestion optimalisée assistée par ordinateur.
Les programmes de gestion optimalisée ont été implémentés dans un réseau de distribution d'eau belge, à partir des informations récoltées depuis des châteaux d'eau, des stations de pompage et des vannes motorisées. Le réseau est d'abord simulé avant d'être optimalisé.

PHILOSOPHIE GENERALE

La formulation du modèle mathématique est issue d'une méthode hybride provenant de considérations topologiques et de la deuxième loi de Kirchoff.
L'algorithme de simulation tient compte des éléments du réseau comme les noeuds, les jonctions, les stations de pompage, les réservoirs et les vannes motorisées. A partir de ces données et de la méthode hybride, l'algorithme calcule les débits et les pressions ainsi que les surplus de production et les endroits où les stocker.
Une fonction coût est définie pour la gestion optimalisée. Elle est fonction du coût de la consommation énergétique des stations de pompage (essentiellement la différence entre le tarif électrique de jour et de nuit), de la perte de charge dans le réseau et du coût de surstockage dans les réservoirs.
Les contraintes de travail sont les débits minimum et maximum et les pressions répondant aux impératifs de sécurité.
Les contraintes de distribution tiennent compte des pressions aux noeuds, des débits excessifs et des niveaux d'eau.
L'algorithme créé permet ainsi d'utiliser une optimalisation dynamique, de préférer les tarifs de nuit pour stocker l'eau dans les réservoirs et de minimiser la fonction coût.
Pour ce faire, un système d'acquisition des données les plus significatives et d'archivage a été installé afin de déterminer l'évolution temporelle de celles-ci.

LA STRUCTURE DU PROGRAMME

Le programme conversationnel présente beaucoup d'avantages : l'entrée des données se fait par un système de menus, seules les informations plausibles sont acceptées et celles-ci peuvent être facilement modifiées.
L'utilisateur peut disposer de deux versions; soit le programme conversationnel complet de simulation et d'optimalisation, soit les programmes de gestion permettant de minimiser la fonction coût.

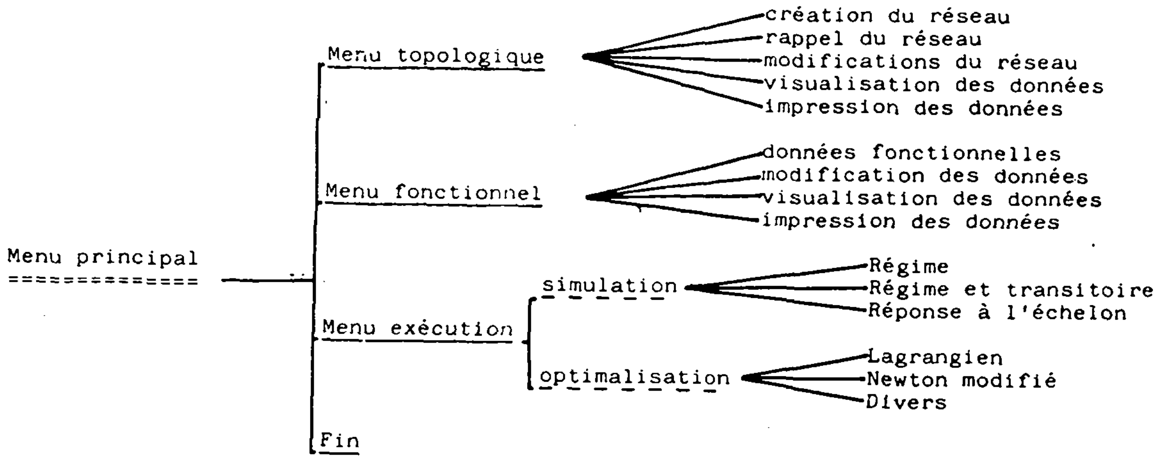


Fig. 1 Bloc diagramme.

Ces programmes ont été développés d'abord sur un Vax 785 et ensuite sur un micro-ordinateur associé au système d'acquisition permettant de travailler en temps réel.

UN CAS CONCRET : LA REGIE DES EAUX DE CHARLEROI

Historiquement, la région actuelle du grand Charleroi était alimentée en eau potable par une série de petits réseaux indépendants. Ceux-ci ont fusionné en un grand réseau urbain, héritant de la conception et de l'agencement initiaux. Ce réseau de 700 km de conduites n'est pas maillé, il y a peu de consommateurs directs (structure en ligne) et il est possible manuellement d'interconncter des lignes indépendantes via des châteaux d'eau pour compenser l'arrêt accidentel d'une station de pompage.
La Régie des Eaux de Charleroi distribue chaque jour 40.000 m3 d'eau à 61.000 abonnés dont 44 % est fourni par 3 stations de pompage et 3 galeries captantes, le restant étant fourni par d'autres régies - 15 châteaux d'eau et réservoirs assurent le stockage.
Le système d'acquisition de données permet à chaque instant via des lignes permanentes de connaître l'état des stations de pompage (débits, pressions, niveaux, taux de chlore, présence haute et basse tension, courant des pompes,...) et via le réseau commuté, l'état des réservoirs.
Le micro-ordinateur, en fonction de ces informations, envoie les ordres de marche/arrêt des pompes et des vannes motorisées. Le protocole de transmission utilisé permet de s'assurer et toute circonstance de la validité des données et indique toute anomalie.
Les stations de pompage et les réservoirs principaux ont été automatisés dans un premier stade afin de récolter le maximum d'informations sur le fonctionnement. Pendant cette période d'acquisition de 6 mois, les pompages ont été directement asservis aux niveaux d'eau des réservoirs.

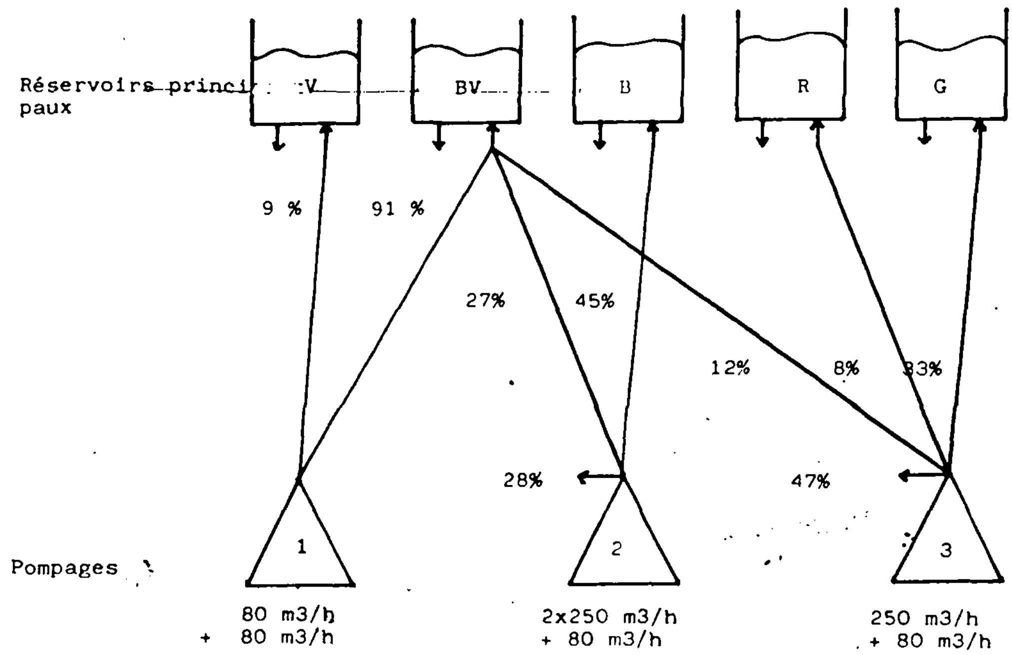


Fig. 2. Schéma des ouvrages du réseau de Charleroi.

CONCLUSION

La télégestion d'un réseau de distribution d'eau est une application relativement récente. La complexité et la diversification des problèmes rencontrés l'explique assez.
Au stade actuel, l'automatisation complète du réseau de Charleroi est en cours, l'exploitation de l'archivage a permis de dégager les grandes lignes de l'optimalisation.
Un des aspects fondamentaux du système a été donné à la sécurité de transmission tant des données que des commandes, et les résultats obtenus confirment la fiabilité de la télégestion.

INFORMATION MANAGEMENT TO THE YEAR 2000

by J. Frateur,
Chief Adviser,
Antwerpse Waterwerken,
B-2000 Antwerp, Belgium.

The quality of our companies will be determined by the way we deal with information. Everything changes. Nothing remains as it is.

FROM DATA TO MANAGEMENT INFORMATION

People and Organizations show an ever increasing hunger for information and they must assimilate a stream of data in order to be able to fulfil their tasks.
This data stream must be processed into workable information, which must be then turned into meaningful, efficient management information.

OUR TASK

The key task of our enterprises remains, in the light of the 21st century : to supply good quality drinking water in a continuous way and in sufficient quantities. This statement implies numerous highly technical aspects which are all challenges to engineers and chemists and will undoubtedly be raised extensively in the course of this symposium.
But our task, which consists in meeting the primary needs in matters of water, reaches further : presently and towards the year 2000, our consumers, who are our customers, will continue to have the right :

1. to a water supply against the best economical conditions;
2. to a consumer-friendly service, within the limits of the possibilities granted by the available technical means and the justified expectations of the customers, who, more often than we assume, compare our services with those rendered by similar authorities.

Are these elements standing values in the strategy as deployed by the management and, if they are, do these concepts come to light in the tactical and operational planning?

ADMINISTRATION IS IMPORTANT

Up to 95 % of the contacts between our customers and our services are, in the broader sense of the word, "administrative" ones, meaning that they are based on providing information. The quality and the speed with which information is given, determines strongly the quality of our global services rendered. The attitude of the population towards distribution services is strongly based on experiences with bills, reminders, letters, meter readings, inspections, contracts, telephone calls, printing matter, notices, the execution of works, etc.
Here also new ideas, possibilities, theories and (payable) techniques and technologies show up. Do we, in our fundamentally technically oriented enterprises, attach sufficient value and attention to these aspects?
A strategy and tactical and operational planning towards the year 2000 are, also on this level, essential.
As much as for the production, the distribution and the laboratories, the "administrative" sector and the information management should be given more space, i.e. more time, more people and money should be freed for study, research, analyses, organization and education. Until recently, the increase of the productivity in the white-collar sector did not seem relevant at all. Only operational and transactional operations were automized, later computerized. Also on the level of tactical control by both the services concerned and the responsible people of the services, an important part of the structural procedures were integrated. The decision making level however is, still nowadays, stepmotherly treated. Few computer capacity was engaged in both the top and middle management to obtain decision preparing or decision supporting information or facilities.
The administration and the "administrative" data processing have long been considered as inevitable evils, for which the investments of people, material en education remained limited as a result of the lack of a mathematically demonstrable yield. The costs were considered as a separate entity and often not directly experienced as useful (or necessary) for the sound functioning of the entire business system. Therefore many operational but even management decisions had to be based, in the absence of better solutions, on rather vague intuition an prescience.
Presently however, a new evolution is developing. More and more, one recognizes the value and the possibilities offered by information. This consciousness-raising process is accelerated by the obvious possibilities which present new hardware and, even more, new software facilities.

EVOLUTION TO INFORMATION MANAGEMENT

The evolution of mechanization via the information stage towards "INFORMATION MANAGEMENT" will form a basic mainstay for further business success.

HARDWARE AND SOFTWARE

The building up of corporate databases and the acquisition of adapted exploitation tools for specialists and end-users will prove to be essential to that effect. Personal computing facilities, supported by corporate databases, should be placed at the disposal of all management levels and, in an adapted version, also to the complete executive sector of the company. Ever stronger and quicker processors of the mainframe, mini and micro type - and where are the limits ? -, will make this undoubtedly possible. Optical disks, bubble-memories and other storage means will take care of the required environment. New developments in matters of software, integrated or no in new hardware facilities, will simplify the manipulation needed to turn the available data into relevant information.
Thereto, it is important to indicate the evolution of the prices of hardware and software. In the past, it has proved to be much easier to obtain funds for hardware than it was for software because the latter was less tangible and less adopted as assets. Nevertheless it becomes more and more the software which we are engaged with and bound to; software results in cumulative investments such as man-years of development work of specialists, typists and staff. This makes the choice extremely important and when the purchase is considered, the price of the software should be only one aspect and, in many cases, even an aspect of minor importance.
Furthermore, telefax, videotex, tele-metering and several other systems are bound to change the relations and the connections with the customers.
Internally, the paper shop should be broken down. Paperless is an utopia, less paper is not. A general use of terminals and data bases will allow such evolution, but only on condition that our organization, our way of working, our authorizing procedures, etc. are thoroughly altered.
Most probably reality will surpass fantasy as for the speed with which new and often unexpected applications in informatics will become available.

ORGANIZATION - PEOPLE

Hardware and software applications for fundamental adaptations are already available now or will be soon; we have no doubts about that. They are already partially known, partially predictable... But how about our staff? How about our structures?
Hardware and software are earlier replaced than organizations, easier also than men.
Hardware and software are being depreciated over four years. The "brainware", people are not depreciated. They are taken on and should feel well during forty years.
The success of information management will less depend on the trademark or the type of the computer, nor on the degree to which the data base is relational, but rather on the quality of information analysis and functional analysis, on the degree in which the built information network meets the real needs on the one hand, and on the training, the retraining, and the occupational resettlement on the other hand. Perhaps the success depends still more on the motivation of the personnel concerned. This is not only true for specialists but applies to all users : the lower staff, those responsible for the teams, the middle and top management. Inevitable, you will be confronted with "transition cases" which should be accepted as part of the price to pay to make the train and to continue realizing the objectives set by the company.
All this requires planning, strategy; requires people, kwowledge, time and money, and therefore a revision of notions related to "investments" is necessary. Research, analysis, training, and retraining are also "investments" and necessary ones at that. They are essential and inseparately linked to each investment in new present and future technological hardware and software programmes.
Any proposal for investment in matters of hardware or software which fails to include or is not preceded by investments in analyses, in training of specialists and users, and in implementation, should be refused by the top management. If no funds are available for these aspects, then reconsider and reduce the project until they are.
"There are no problems, there are just men". Problems are not raised by hardware nor by software in the first place. Our most important investments, and those with the longest run at that, are people and they will always be.
A certificate is now the end of the beginning. Permanent training is necessary: preventive, corrective, creative.
Therefore we should provide the necessary housing facilities; we should stimulate, promote and keep up the inquisitiveness of our personnel and its motivation. We are in high need of creativity, of creative co-workers, collaborators who have ideas. We should stimulate creative talent, reward it, valorize it.

CONCLUSION

In the evolution to Information Management, our main concern, as we approach the year 2000, will not be as much the hardware or the software, but rather the so-called brainware and the organisational aspects of the procedures. CPU-power without adapted "brainpower" and without adapted organizations, has almost no value.
This is not always and everywhere self-evident. We must take decisions in order to enable our personnel, our structures, and our organization to continue to fully exploiting the possibilities of informatics.
To contribute to this consciousness-raising process seems me an important and fascinating task for the IWSA.

INVESTIGATION ON THE REMOBILIZATION OF HAZARDOUS MATERIAL BY DUMPING OF WATER WORKS SLUDGES

H. Eckhardt, K. Haberer

ESWE-Institut für Wasserforschung und Wassertechnologie, Wiesbaden,
Federal Republic of Germany

ABSTRACT

The described laboratory tests are suitable for the simulation of extreme leachability conditions and respective concentrations of leakage water, as borne out by good correlation with operational data. Considering the content and the chemical bindings of trace elements the majority of the investigated water works sludges can be called hazard-free.

KEYWORDS

Trace elements; organic compounds; decrease of pH-value; influence of complexing agents; changing of oxidation conditions.

INTRODUCTION

During dumping and natural dewatering the trace elements and organic compounds fixed in water works sludges may be remobilized by environmental influences. The most important influences are:

- decrease of pH-value
- change in the oxidation(redox)-conditions
- complexing agents.

MATERIAL AND METHODS

For the investigation several sludges from different German water works were used for tests under laboratory as well as operational conditions. The following laboratory methods were developed and standardized:

- leachability test to ascertain dependence on pH-values,
- leachability test to evaluate the effect of complexing agents,
- tests to find the effect of changing oxidation conditions,
- pressure filtration test,
- tests to unravel the mode of chemical binding of trace elements to the solid fraction.

The experiments are performed using standard methods; thus, it is possible to compare the results obtained with different sludges.

The accompanying studies under operational conditions include the running of a pilot plant and observations on drying beds and dumping grounds. The laboratory results are compared to actual operational data, in order to give hints as to whether the tests are transferable.

The investigations were carried out with a sludge, resulting from the flocculation process of surface water treatment with ferric-chloride after subsequent sedimentation.

RESULTS

DECREASE OF pH-VALUE

The investigations concerning the decrease of the pH-value show for the most sludges, that only at $pH < 3$ the release rates of copper, chromium and nickel increase (see fig. 1). Even at $pH = 2$ the maximal

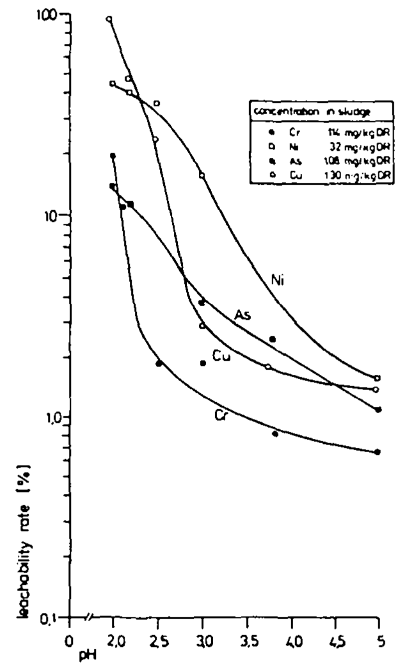


Fig. 1. Influence of pH-value on remobilization of trace elements

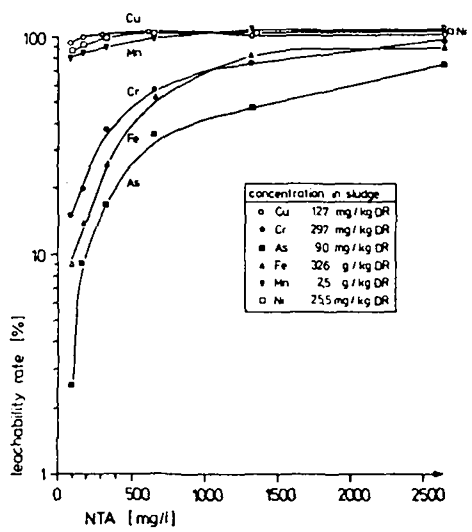


Fig. 2. Influence of NTA concentrations on remobilization of trace elements

leachability rate for arsenic is only 10 %. The investigations concerning the chemical forms confirm, that the binding of arsenic in the tested sludges is more stable than the binding of other elements. Therefore the remobilization rate of arsenic is rather low. The mode of binding of copper and nickel is relativly weak. The experiments performed under operational conditions confirm the data obtained in the laboratory. Of course, the release rates are significantly lower than in the laboratory, but the qualitative behaviour of the trace elements is transferable.

CHANGING OF OXIDATION CONDITIONS

To investigate the changes of the oxygen conditions we measured the parameters redoxpotential, NH_4^+, NO_2^- and enzyme activities. Strong anaerobic and aerobic conditions were obtained by definite adjustment of the redoxpotential. Apart from these conditions the trace elements were not remobilized when constant redoxpotentials were maintained. Frequent changes between anaerobic and aerobic conditions, however, led to a higher mobility. Arsenic behaved similar to iron and showed in this test the highest stability.

INFLUENCE OF COMPLEXING AGENTS

The experiments on the influence of synthetic and natural complexing agents were performed with humic acid, NTA and EDTA. Fig. 2 and 3 show the results of laboratory tests on the investigated flocculation sludges, which contain high amounts of iron. It is obvious, that a NTA and EDTA concentration of several hundred mg/l is necessary to remobilize more than 50 % of the trace elements. The analyses of the liquid sludge phase showed NTA concentrations of about 160 ug/l and EDTA concentrations of about 60 ug/l. The high NTA concentrations are due to an increase by a factor of 30 during flocculation/sedimentation process, whereas EDTA is not significantly concentrated. Presently a danger of remobilization of trace elements out of water works sludges is not to be expected.

Remarkable are the relativly high remobilization rates for trace elements resulting by the addition of humic acid. Even humic acid concentrations of about 10 mg/l result in remobilization rates of about 10 % and more, as shown in fig. 4. Humic acid effected conspicuously high remobilizations for arsenic and iron. In leachability tests by EDTA, NTA and a decrease in pH these elements (As, Fe) were less remobilized compared to nickel, copper and chromium. The remobilization caused by NTA and EDTA is nearly the same; in contrast, humic acid effects, rather in small concentrations, high remobilization rates.

TRANSFER OF LABORATORY TESTS TO OPERATIONAL DATA

Although the leachability test is the last suitable of all described tests in order to simulate the processes in a dump, it gives a very good evaluation of the concentrations in the leakage water. This is demonstrated by a comparison between the results of the leachability test and the result of leakage water from dumps and drying beds.

The concentration of trace elements in pressure filtrate correlates well with the management data. Because of the exact separation of liquid and solid parts by the pressure filtration test the whole interstibal water of the sludge is obtained, which resembles the natural dewatering on dumps and drying beds.

In principle, the leachability test gives nearly the same data compared to the values analysed in leakage water from water works sludges on dumps and drying beds under present conditions, i. e. without decrease of pH-values and without the addition of complexing agents. Thus, the results of this test can be taken as a basis for estimating the concentrations of trace elements in leakage water from water works sludges on dumps and drying beds.

ORGANIC COMPOUNDS

Methods for analysing organic micro pollution in water works sludges and leakage water were developed.

For measurement of PAH 30 g of DR were leached with Toluene in a Soxleth. The determination was performed with HPLC with diode-array-detection. By this protocol the PAH's Phenanthren, Fluoranthen, Benzo(b)fluoranthen, Benzo(h)fluoranthen, Benzo(a)pyren, Benzperylen, Indenopyren were detected in the sludges in concentrations of 0,1 - 0,5 ng/kg DR. In the corresponding leakage water and leaching water no PAH's were detected.

For the determination of N- and P- containing pesticides 1 l of sludge water was adsorbed on RP-C 18-cartridges eluted with acetone and measured using Gas Chromatography and Nitrogen-Phosphorousdetection. The pesticides Atrazin (average 8 ng/l), Terbotylazin (average 22 ng/l) and Prometryn (average 15 ng/l) were detected in the sludge water.

In the corresponding leakage water and the leaching water no pesticides could be detected.

As far as organic compounds are concerned, the sludges of surface water treatment can be classified as more dangerous compared to the sludges of groundwater treatment.

SUMMARY

Summarizing, we can conclude that as far as the pH-value of the acid precipitation, the redoxpotential and the concentrations of complexing agents in surface and ground water will not change substantially, an acute danger by remobilization of trace elements is not to be expected.

The above described laboratory tests are suitable for the simulation of extreme leachability conditions and resprective concentrations of leakage water, as borne out by the good correlation with operational data. Considering the content and the chemical bindings of trace elements the majority of the investigated water works sludges can be called hazard-free. A critical release may result with sludges originating from extremly contaminated surface or ground waters, as well as from filtration or activated carbon treatment. Regarding the organic compounds, sludges of surface water treatment are more contaminated than sludges from ground water treatment.

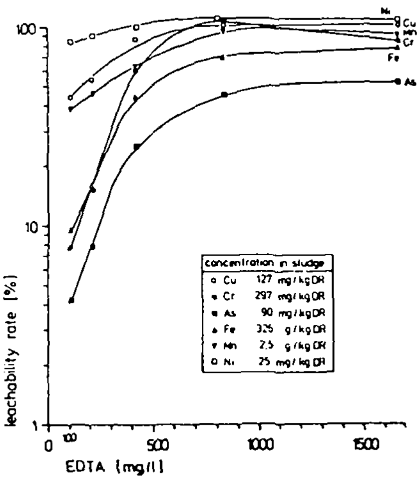


Fig. 3. Influence of EDTA concentrations on remobilization of trace elements

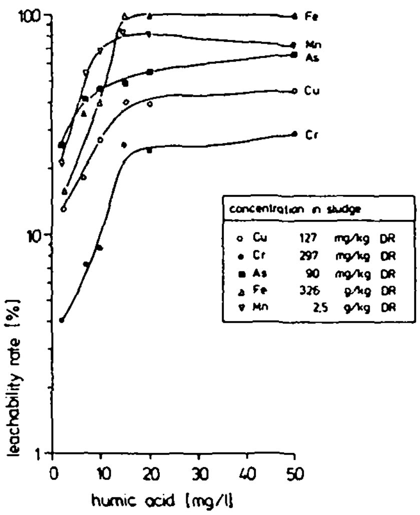


Fig. 4. Influence of humic acid concentrations on remobilization of trace elements

DYNAMIC SEPARATION

K. Hashimoto* and N. Tambo**

*Division of Research and Development, Suido Kiko Kaisha, Ltd., Tokyo 103, Japan
**Department of Sanitary and Environmental Engineering, Hokkaido University, Sapporo 060, Japan

ABSTRACT

Historically, improvement of sedimentation basin performance has been carried out in the category of overflow rate theory. Extreme development of this design principle are seen in tube settler (in U.S. practice) and multiple-stage slant-board settler (in Japanese practice) which have the lowest overflow rate with laminar flow regime. The authors proposed a new dynamic separation method and succeeded to overcome the limit of the conventional overflow rate improvement. This is the finned channel separator in which parallel fins perpendicular to the direction of flow are placed at an angle of incidence on slant boards. Theoretical and experimental studies were carried out in order to establish the new dynamic separation method as a practical technique with sound theoretical basis. Based upon the studies, more than 200 finned channel separators are now working in various solid-liquid separation processes as well as in water works treatment operations. By this proposal, the bulk of separation technique can step into the category of dynamic separation which drastically outreaches the conventional static separators, that is, ideal sedimentation concept.

KEYWORDS

Dynamic separation; Finned channel separator; Sedimentation tank; Flow visualization; High performance floc separator.

INTRODUCTION

Basically, the gravity sedimentation processes are continuously operated under static flow conditions. Hazen developed a relationship between batch and continuous operations in the sedimentation operation by introducing basic concept of the ideal settling basin.[1)] Camp demonstrated that basin retention time is not a factor for the ideal basin.[2)] A more general proof, not assuming the ideal but allowing flow vectors to vary with depth, was published by Fitch.[3)] From these studies it has been accepted as a theory that overall solids removal is a function of the amount of clarified overflow and basin area i.e. overflow rate. Thus, historically, improvement of sedimentation basin performance has been based on the principle of attaining a much lower overflow rate in a given tank volume with a laminar flow condition at lower Reynolds number.

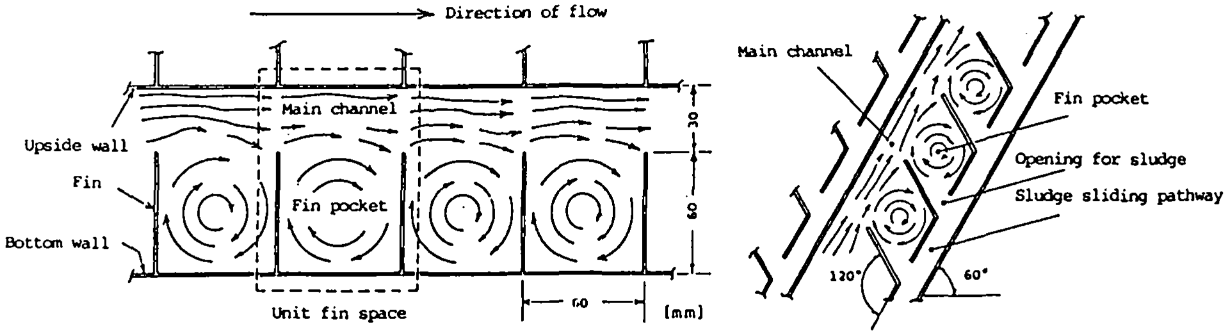
When a sedimentation process is continuously operated, particles show very much complex motions because of the complex hydraulic behaviors in the sedimentation basin. The particles in a liquid flow will be moved not only with gravity but also with other forces such as drag and inertia. But the conventional approach to improve sedimentation basin performance has emphasized only the static scheme to attain a much more laminar condition in order to avoid the influence of drag, inertia and other forces except gravity. If, on the contrary, one attempts to use these forces to accelerate the separation as a complement of gravity, a new dynamic scheme could be posed.

From this concept, the authors proposed a new dynamic separation process which is called as the finned channel separator. By the finned channel separator, the authors succeeded in overcoming the limit of overflow rate improvement. Much higher efficiency of floc separation was attained by placing parallel fins perpendicular to the direction of flow at an angle of incidence on slant boards and admitting flocs into numerous wake vortex streams behind the fin. The dynamic driving forces added to the conventional gravitational separation accelerate the separation drastically.

TYPES OF FINNED CHANNEL SEPARATORS

To utilize other forces of separation than gravity in achieving separation, the finned channel is introduced into the floc separation process. The basic unit of the finned channel consists of a fin pocket, surrounded by a pair of fins and a bottom wall, and a main channel between an upside wall and the fin pocket, as schematically shown in Fig. 1. This basic unit of the finned channel is defined as "unit fin space".

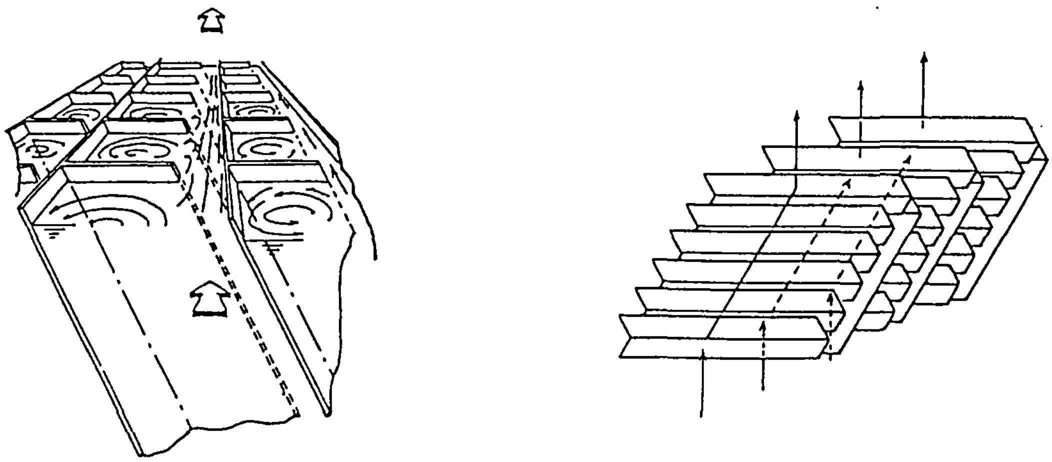
The two standard types of finned channel separator were assembled for this study. The horizontal finned channel separator is proposed for horizontal separation tanks, and is constructed of parallel fins and parallel slant boards. The fins are placed on the parallel slant boards in an upright position perpendicular to the direction of the main channel flow. Similarly, the upflow finned channel separator is applied to upward-flow separation tanks. The upflow finned channel separator has these features of construction:



Horizontal finned channel

Upflow finned channel

Fig. 1. Schematic finned channel.



Horizontal finned channel separator

Upflow finned channel separator

Fig. 2. Composition of finned channel separators.

a sludge sliding way is installed just under the bottom of each finned channel, a slid leading to the sludge sliding way is provided in the bottom wall of each unit fin space, and the angle of incidence of fins is 120 degrees to the stream so as to transport the flocs deposited on the fins. Horizontal and upflow finned channel separators are schematically shown in Fig. 2.

EFFECT OF THE FINNED CHANNEL ON FLOC REMOVAL

To find what degree of floc removal improvement is achieved by introducing the finned channel, comparative experiments between the dynamic finned channel separator and the conventional static settlers were carried out under the same flow conditions. For the horizontal-flow operation, a twin treatment plant, in which the horizontal finned channel separator and the slant-boards settler are equipped in parallel, was used to operate them simultaneously. The nominal treatment capacity of each unit is 150 m^3/day. Similarly, a square-shaped upward-flow tank was used to compare the upflow finned channel separator with the tube settler under the same flow conditions. A treatment capacity of 100 m^3/day is the standard rate of flow for the experiments. Some examples of the results obtained are graphically shown in Fig. 3.

On the basis of comparative experiments, it was proved that the finned channel achieved a distinct improvement in floc removal rate compared with the usual multi-layered laminar scheme based upon the overflow rate theory. A retention time of only 5 to 6 min was needed to perform the desired separation. By the such short retention time to be required, equipment scale can be sharply reduced to one-forth to one-fifth of the slant-boards or the tube settler with the finned channel separator.

FLOW PATTERN OF THE FINNED CHANNEL

Identification of the flow pattern of the finned channel was attempted in order to establish the separation mechanism clearly and to find the basis for theoretical design. Fig. 4 shows hydrogen bubble photographs obtained in a horizontal finned channel. Nearly the same hydrogen bubble behavior was observed in the upflow finned channel. Based on the photographs, the flow pattern of the finned channel could be diagrammatically depicted as shown in Fig. 5. From the visualization experiment, it became clear that the finned channel flow consists of three typical flow state regions; the parallel laminar flow region with a certain width along the upside wall of the main channel, the circulating laminar flow region of the fin pocket, and the fin wake vortex street in the boundary between the main channel and the fin pocket. The characteristic behavior of the vortex street is the key factor for the promotion of separation as will be discussed in the following section. The vortexes forming by way of boundary-layer separation hit the top of the upstream side of the downstream-ward fin, then roll into the fin pocket.

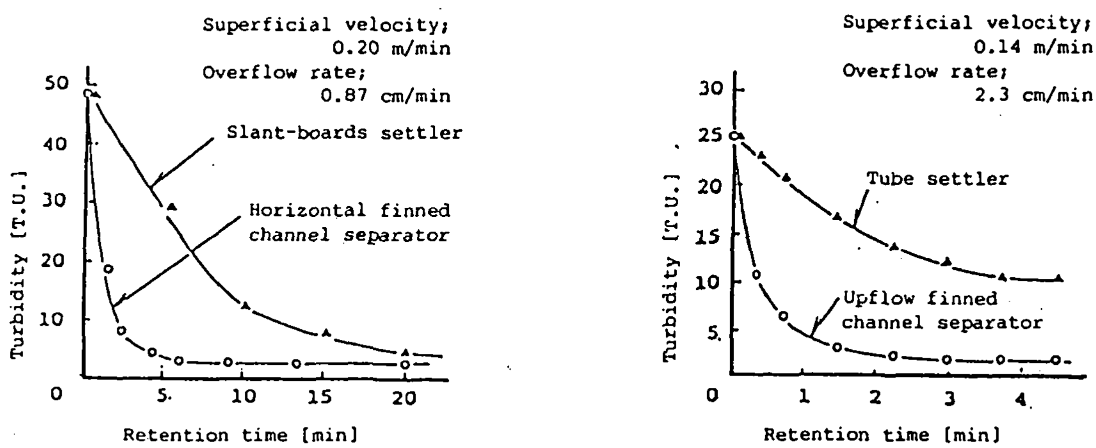


Fig. 3. Results of comparative experiments.

KINETIC MODEL OF FLOC SEPARATION

From the visualization of the finned channel flow and the behavior of flocs recorded on video tape, it is satisfactory to consider that the floc separation occurs in the seven steps, as schematically shown in Fig. 6.

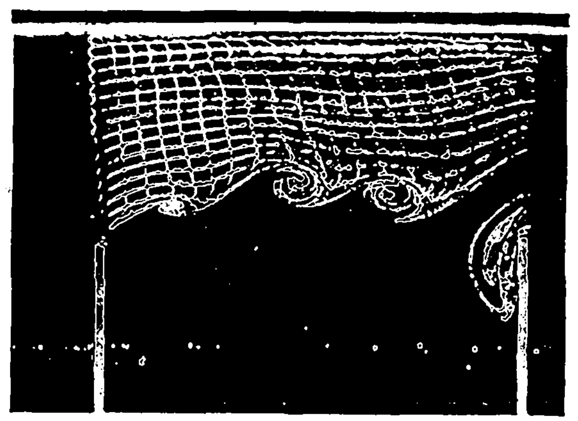
To establish a mathematical model of floc separation, the unit fin space is divided into three zones according to the flow pattern, then control sections are provided in the i-th unit fin space, and each transfer rate through the individual section is presented by the symbols shown in Fig. 7.

In Fig. 7, individual symbols indicate the following: q_{i-1}: input of floc particles to the i-th unit fin space, [mg/cm•sec]; $q_{g,i-1}$: input of floc particles to the i-th parallel laminar zone from the (i-1)-th unit fin space, (= $q_{i-1} - q_{m,i-1}$), [mg/cm•sec]; $q_{m,i-1}$: input of floc particles to the i-th fin wake zone from the (i-1)-th unit fin space, [mg/cm•sec]; $m_{g,i}$: rate of floc particle transportation from the i-th parallel laminar zone to the i-th fin wake zone by settling, [mg/cm•sec]; m_i: rate of floc particle transportation from the i-th fin wake zone to the i-th fin pocket zone by the action of whirling wake, [mg/cm•sec]; q_i: output of floc particles from the i-th unit fin space, i.e. the remaining floc suspension at the end of the i-th unit fin space and the input of the (i+1)-th unit fin space, [mg/cm•sec]; $m_{b,i}$: rate of floc particles transportation from the i-th fin pocket zone to the bottom of the i-th unit fin space, i.e. the overall rate of removal, (= $q_{i-1} - q_i$), [mg/cm•sec].

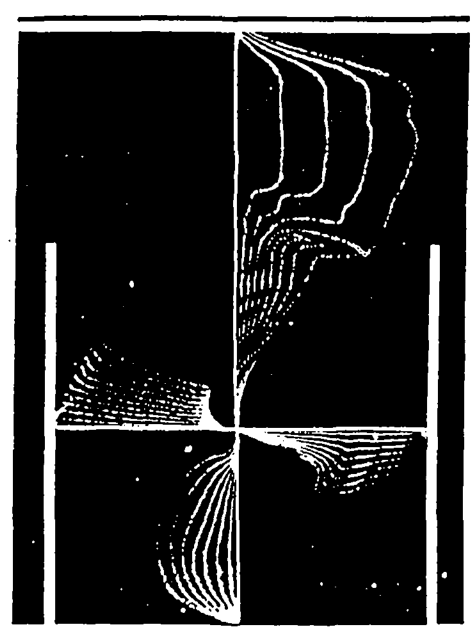
The gravitational separation step from the circulating flow to the bottom wall is not the rate-determining step of separation because of its much higher transfer rate compared to the other steps (m_i = $m_{b,i}$). From the relations presented in Fig. 7, taking the material balance on the floc particles transferred across each control section with the unit width gives the following equation consequently.

$$q_i = \int_0^{w_0}\left(vD - \alpha v\Delta - \alpha v(D-\Delta)\frac{w}{w_0}\right)f_{i-1}(w)dw + \int_{w_0}^{w_{max}}(1-\alpha)vD\, f_{i-1}(w)dw \qquad (1)$$

where v: mean velocity of the main channel flow, [cm/sec]; w: settling velocity of flocs, [cm/sec]; $f_{i-1}(w)$: input settling velocity distribution function to the i-th unit fin space, [mg•sec/l•cm];

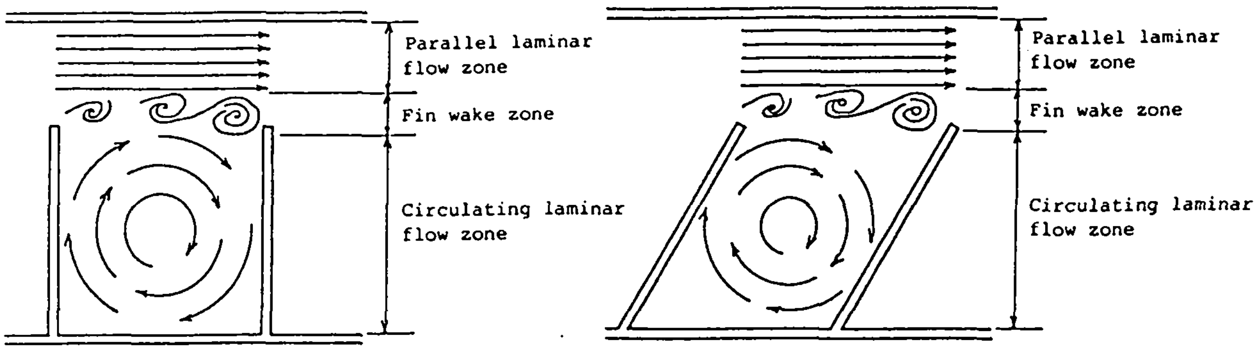


Flow pattern of a main channel



Integrated time lines of a unit fin space

Fig. 4. Hydrogen bubble photographs obtained in a unit fin space.



Horizontal finned channel — Upflow finned channel

Fig. 5. Flow pattern of the finned channel.

w_0: overflow rate of the i-th main channel flow zone, [cm/sec]; w_{max}: maximum settling velocity of flocs, [cm/sec]; α: floc transfer ratio from the fin wake zone to the fin pocket zone, [-]; D: thickness of the main channel, [cm]; Δ: thickness of the fin wake zone, [cm].

In fact, the thickness of the main channel laminar flow, $(D - \Delta)$, fluctuates, due to the periodical variation of the fin wake vortex street. The flocs contained in the parallel laminar zone are forcibly taken into the fin wake zone due to this periodical action of the vortex street. This random floc transfer step to the fin wake zone can be estimated as a stationary process by introducing a hypothetical mean thickness of the parallel laminar flow zone, $(D - \Delta)$, multiplied by a correction factor positive and less than 1, β, [-]. After this correction, the stationary overflow rate involving the fluctuation of the fin wake becomes

$$w_0 = \beta(D - \Delta)v/\ell \qquad (2)$$

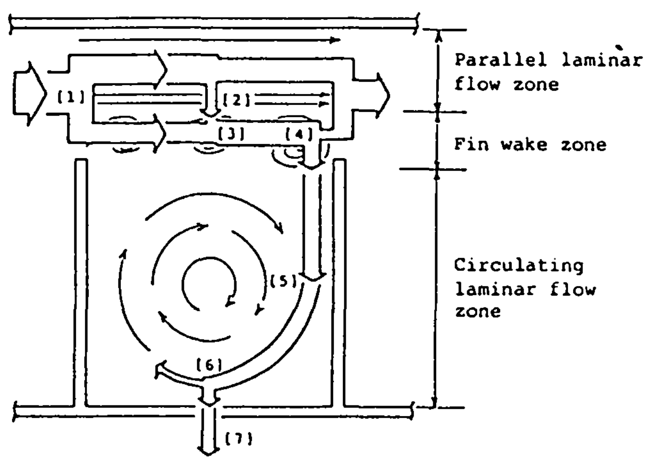


Fig. 6. Separation steps of the finned channel.

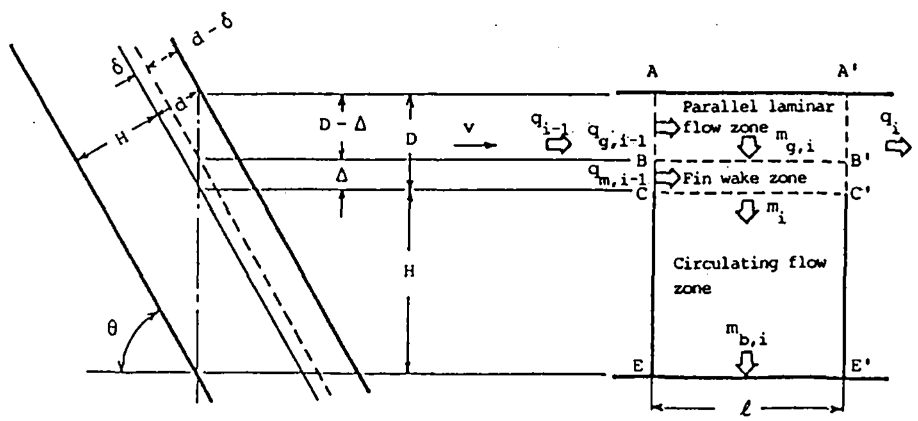
where, ℓ is fin spacing of the unit fin space, [cm]. Substituting Equation (2) into (1) gives

$$q_i = \int_0^{w_0} vD(1 - \Lambda)f_{i-1}(w)dw + \int_{w_0}^{w_{max}} vD(1 - \alpha)f_{i-1}(w)dw, \qquad \Lambda = \alpha\frac{\Delta}{D} + \frac{\alpha\ell}{\beta vD}w \qquad (3)$$

From Equation (3), the output floc concentration from the i-th unit fin space, $C_i = q_i/vD$, is finally given as a function of the inlet settling velocity distribution, $f_0(w)$:

$$C_i = \int_0^{w_0}(1 - \Lambda)^i f_0(w)dw + \int_{w_0}^{w_{max}}(1 - \alpha)^i f_0(w)dw \qquad (4)$$

Making a comparizon between the simulated results from this mathematical model and the observed results, the coefficients presented in the model were evaluated and the validity of the model was confirmed, as shown in Fig. 8.



Cross section — Londitudinal section

Fig. 7. Material balance of the i-th unit fin space.

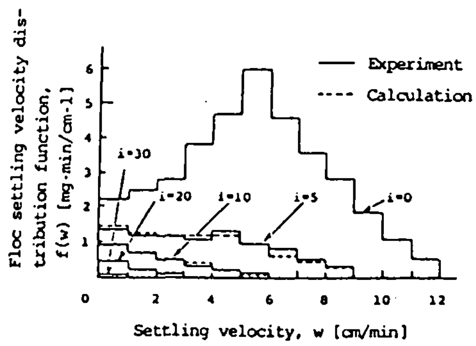


Fig. 8. Variation of floc settling velocity distribution (experiment and calculation).

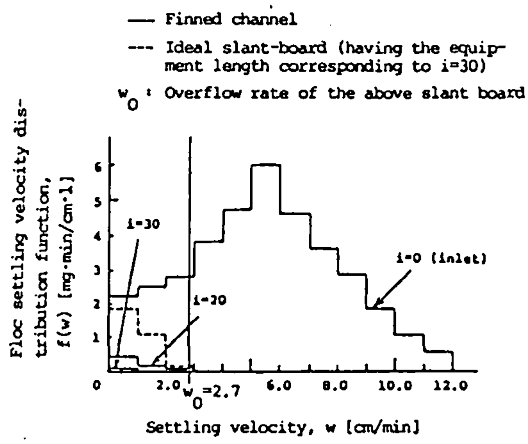


Fig. 9. Improvement of floc settling velocity distribution by the finned channel (compared with an ideal slant board).

Compared with an ideal slant-boards settler with the same board distance and the same overflow rate as the finned channel separator, the difference of performance was further made clear by way of the calculation of settling velocity distribution with respect to the flocs remaining in the finished water(Fig. 9).

SIMULATION OF VARIOUS SEPARATION PROCESSES

For various kinds of suspension, simulations have been carried out according to the proposed kinetic model formula of separation. Some examples of simulation are presented in Fig. 10.

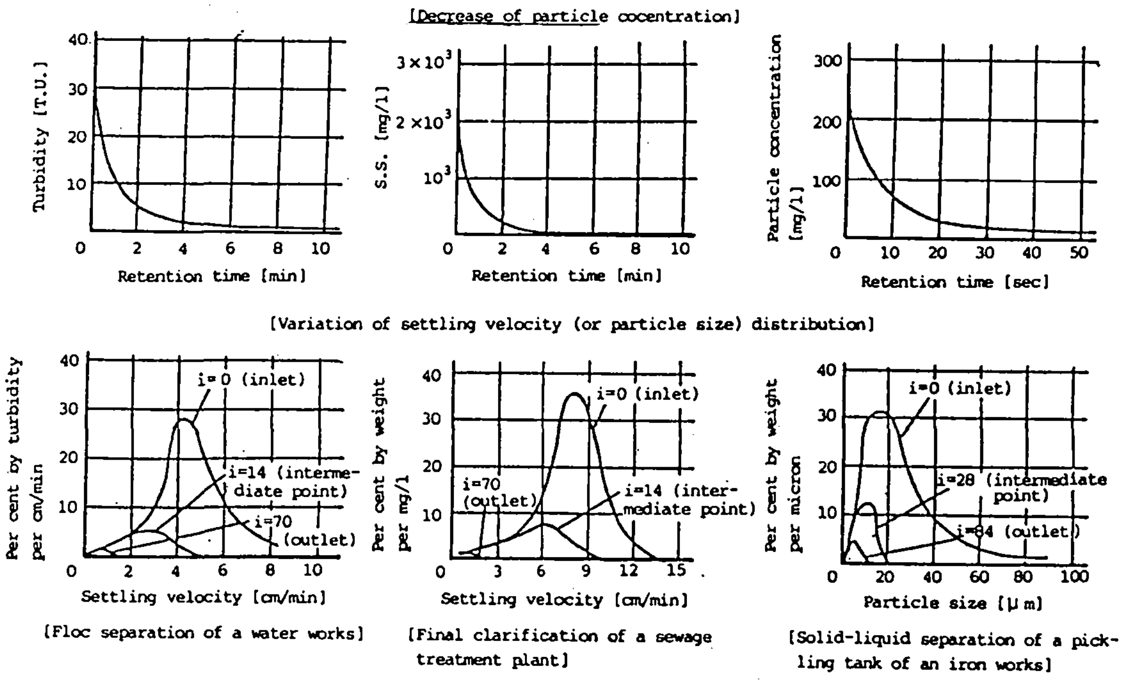


Fig. 10. Simulated results of various separation processes.

ACKNOWLEDGEMENT

The authors gratefully acknowledge to Mr. G. Ozawa, Hokkaido University, and Messrs. T. Hasegawa and T. Onitsuka, Suido Kiko Kaisha, Ltd., for their sincere help in carrying the experimental works.

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The further development in Ozone Application Technology in Potable Water
- Ultra-violet or Ultra-sonic assisted ozonization -

Masuo Kato : EBARA-INFILCO CO., LTD.

Shigeo Yasutake and Norio Makita : EBARA-RESEARCH CO., LTD.

ABSTRACT

One of the latest ozone utilization technologies is the combined oxidation for potable water treatment.
This is to report our experimental results of the Ultra-violet and/or Ultra-sonic assisted ozonization for oxidation.
As a result, Ultra-violet or Ultra-sonic assisted ozonization works effective for the reduction of resolved organic compound in raw water.
For examples, in comparison with existing ozonization alone, the advantages of the combined oxidation are as follows.

1) Ultra-violet assisted ozonization provides odor reduction by 20% more than ozonization alone in the application for filtered water taken from lake water which includes 2-Methylisoboneol of 130 - 160ng/ℓ .

2) Ultra-sonic assisted ozonization provides color reduction by 10 - 20% more than ozonization alone in the application for ground water which includes organic color of 25ng/ℓ.

KEYWORDS

Ozonization, Ultra-violet irradiation, Ultra-sonic irradiation, Manganese Catalyzer, Combined oxidation, 2-Methylisoboneol, Geosmin.

1. INTRODUCTION

The quality of potable water in Japan has been said to be one of the highest in the world.
However, color problem caused by humic or fulvric acid is recently reported in the drinking water taken from some ground water.
The musty odor problem caused by 2-Methylisoboneol or Geosmin is also increasing in the treated water at some water works where raw water are introduced from closed source, i.e. - lake and marsh.
For the solution of these problem, the water treatment with ozone and/or activated carbon has been put into practical use.

Recently, new approach for ozone oxidation has been tried with the combined use of Ultra-violet, Ultra-sonic, Hydrogen Peroxide and chlorine. This paper introduces the pilot-plant experiment for Ultra-violet (UV) assisted ozonization and Ultra-sonic assisted ozonization as part of the combined oxidation for potable water treatment, and also addrress the ozone utilization technology in the future based on our experimental findings.

2. OUTLINE OF PILOT-PLANT EXPERIMENT.

2-1. Ultra-violet assisted ozonization :

Lake KASUMIGAURA which is located 60km in the north of Tokyo is a typical eutrophic lake and a primary source of raw water for potable water.

The musty odor problem has recently been raised in potable water taken from this lake.

The combined oxidation with ozone and Ultra-violet irradiation has been applied for the reduction of organics such as 2-Methylisoboneol, Geosmin, etc. which are considered to be major cause of the musty odor problem.

Fig-1 shows flow chart of the experimental pilot plant.

The experimental conditions are as follows.

(1) Water flow : 50 m^3/d

(2) Retention time of Ozone Contact Tank : 10 - 20 min

(3) Retention time of Combined oxidation with Ozone and UV : 0.5 - 2.5%

(4) Ozone dosage : 0 - 5 mg/ℓ

(5) UV intensity : 0.54 W/cm^2

The analysis of odor components has been made with a gas chromatograph-mass spectrometer.

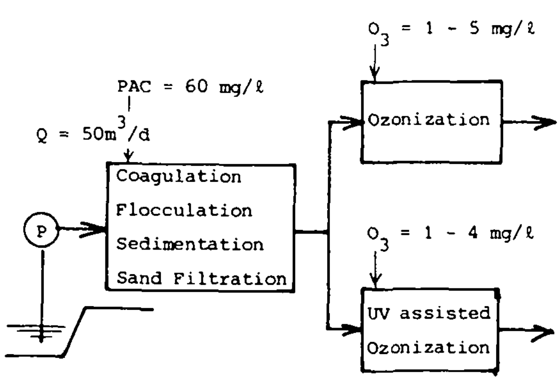


Fig. - 1

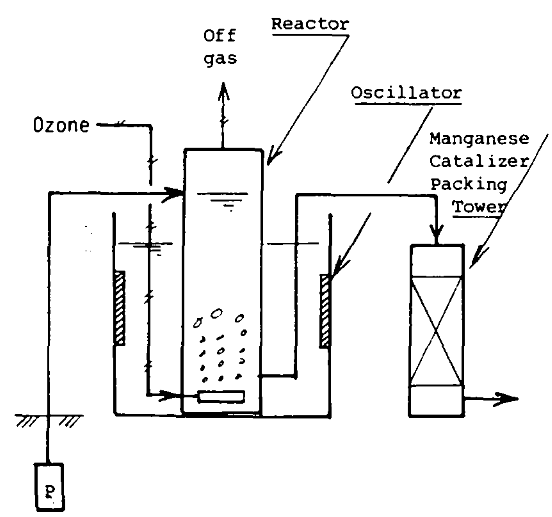


Fig. - 2

2-2. Ultra-sonic assisted ozonization :

Ultra-sonic assisted ozonization/oxidation experiment has been applied for the underground water in the outskirts of Tokyo which includes furvoric acid. In addition, treatment with manganese catalyzer has also studied in this experiment. Fig.-2 shows flow chart of the experimental pilot plant. The testing conditions are as follows.

(1)	Ozone dosage :	1 - 7 mg/ℓ
(2)	Oxidation time with ozone and Ultra-sonic :	2 - 20 min
(3)	Ultra-sonic frequency :	20kHz and 40kHz (automatic change-over every 5sec.)
(4)	Manganese catalyzer :	SV = 500 1/h

3. PILOT PLANT EXPERIMENTAL RESULTS

3-1. The combined oxidation treatment with ozone and Ultra-violet irradiation.

3-1-1 Odor Components Decomposition Effect.

Fig.-3 and Fig.-4 show data for the treatment of 2-Methylisoboneol (2-MIB) and Geosmin. Test results are as follows.

1) Required ozone dosage for 80 - 90% decomposition of 130 - 150 ng/ℓ 2-MIB was about 5 mg/ℓ with ozonization alone. However, it was 3 - 4 mg/ℓ ozone dosage in the combined oxidation with ozone and Ultra-violet irradiation.

2) Required ozone dosage for 100% decomposition of 22 - 32 ng/ℓ Geosmin was about 5 mg/ℓ with ozonization alone. On the other hand, it was eliminated to 3 - 4 mg/ℓ ozone dosage in the combined oxidation with ozone and Ultra-violet.

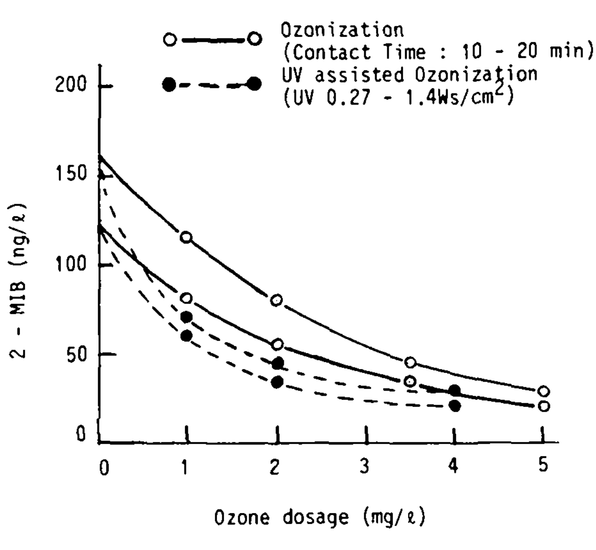


Fig. - 3

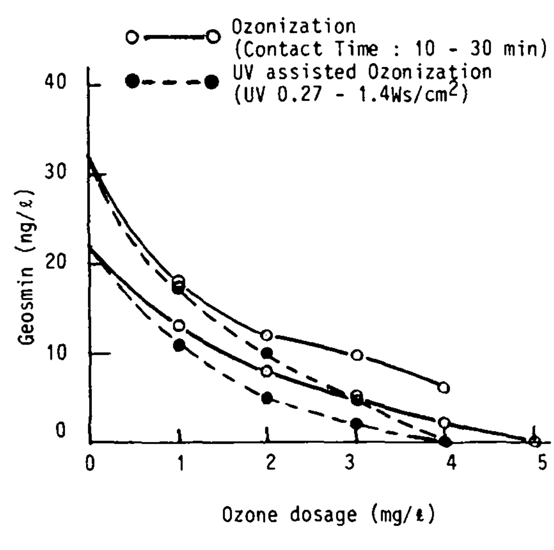


Fig. - 4

3-1-2 Disinfecting effect.

Table-1. shows the experimental data for disinfection. Our findings are as follows.

1) The concentration of E-coli in the-filtered water was 20 - 60 c.f.u./mℓ .
100% disinfection against these E-coli colonies has been achieved in any one of the methods of ozonization alone, UV irradiation alone and UV assisted ozonization.

2) The total plate counts of micro-organisms in the filtered water was 1000 - 5000 c.f.u./mℓ . 2 - 10 c.f.u./mℓ of micro-organisms have been left after ozonization alone and UV irradiation alone. Complate disinfection has been achieved with the combined oxidation of ozone and UV.

Table-1. Disinfecting effects

	Type of process	Ozonization alone			UV assisted ozonization		
	Contact time	10	20	30	0.5	1.4	2.5
	UV Energy ($W.S/cm^2$)	-	-	-	0.27	0.75	1.4
Total plate counts (c.f.u./mℓ)	Filtered water	1000 - 3000			1500 - 5000		
	O_3 Dosage 0mg/ℓ	-	-	-	10	3	ND
	O_3 Dosage 2mg/ℓ	5	2	ND	ND	ND	ND
	O_3 Dosage 3.5mg/ℓ	ND	ND	ND	-	-	-
	O_3 Dosage 4mg/ℓ	-	-	-	ND	ND	ND
	O_3 Dosage 5mg/ℓ	ND	ND	ND	-	-	-
E-coli counts (c.f.u./mℓ)	Filtered water	20 - 60			20 - 60		
	O_3 Dosage 0mg/ℓ	-	-	-	ND	ND	ND
	O_3 Dosage 2mg/ℓ	ND	ND	ND	ND	ND	ND
	O_3 Dosage 3.5mg/ℓ	ND	ND	ND	-	-	-
	O_3 Dosage 4mg/ℓ	-	-	-	ND	ND	ND
	O_3 Dosage 5mg/ℓ	ND	ND	ND	-	-	-

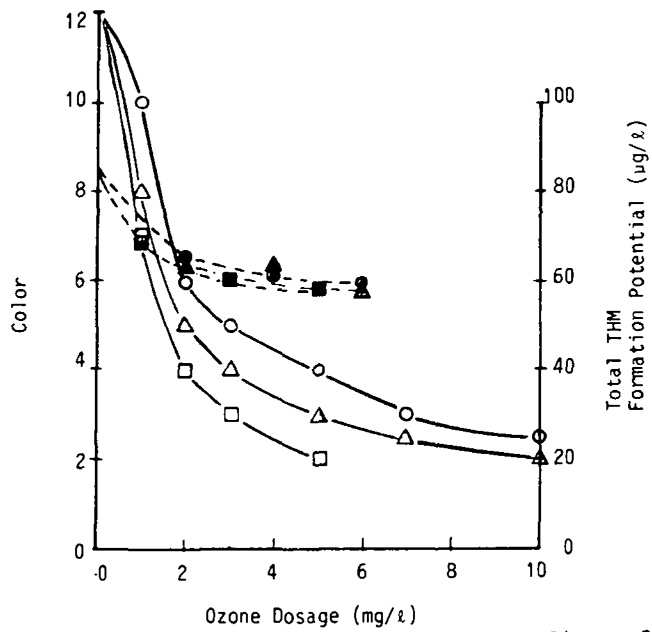
3-2. Combined oxidation with ozone, Ultra-sonic and manganese catalyser.

Fig.-5 shows the reducing effect of color and THM formation potential in underground water, by means of the combined oxidation with ozone, UV and manganese catalyzer. The result are as follows.

1) The combined oxidation with ozone and Ultra-sonic irradiation improves color reduction by 10 - 20%, in comparison with that of ozonization alone.

2) The combined oxidation with ozone and manganese catalizer improves color reduction by 20 - 35%, in comparison with that of ozonization alone. 5/5

3) No significant differences in the reducing effect on THM formation potential were noticed between ozonization alone and the combined oxidation with ozone, Ultra-sonic and/or manganese catalizer.
In any cases, the obtained THM formation potential reducing effect was 30 - 40% reduction.



	Color	Total THM Formation Potential
Ozonization alone	○—○	●---●
Oxidation with Ozone & UV	△—△	▲---▲
Oxidation with O_3 & Manganese catalizer	□—□	■---■

Fig. - 5

4. FUTURE DEVELOPMENT IN OZONE APPLICATION TECHNOLOGY IN POTABLE WATER TREATMENT

In summary, our experimental results show the following.

1) In odor reduction, UV assisted ozonization reduces required ozone dosage by 20 - 40%.

2) In fulvonic color reduction, it has been noticed that the combined oxidation with ozone and manganese catalyzer was effective.

One of the problem of ozonization process is the initial and running cost of the plant. In case of ozonization process for potable water treatment, the size of ozone plant is comparatively large. It is considered that the reduction of required ozone dosage will be appreciated for the decreasing such costs as the initial and the running of ozone plants. The combined oxidation with ozone and UV, Ultra-sonic, or manganese catalyzer can reduce the required ozone dosage.
In this respect, such combined oxidation will be one of the most effective for ozonization process in future.

TUBE FLOCCULATION AND SEDIMENTATION IN A TANK WITH GUIDING VANES

H.-G. Moll

Institute for Water, Soil and Air Hygiene; Federal Health Office Berlin, Germany

ABSTRACT

A water treatment plant in Berlin-Tegel is using tube flocculation and sedimentation in a tank with guiding vanes as consecutive unit operations. The theoretical bases of both steps and first results are presented.

In a water treatment plant in Berlin-Tegel a system was applied which consists out of tube flocculation and sedimentation in a new developed tank. The normal throughput of this plant is 3 m^3/s, the maximum throughput is 6 m^3/s. First results of this combination of unit operations will be presented in this paper.

Flocculation followed by sedimentation constitues one of the oldest processes in drinking water treatment. Stirrers are most commonly used to accelerate flocculation in raw water.

Delichatsios and Probstein (1975) were the first to suggest the use of turbulence resulting from pipe flow as a substitute for stirring devices.

The problem that has to be solved is: what are the proper fluid velocities which should be applied in a tube of given diameter, in order to obtain successful flocculation results.

Figure 1 is a block diagram which shows how the mechanical energy of the mean motion is converted into heat energy in turbulent pipe flow. Both dissipation kinds - direct dissipation E and turbulent dissipation ε - are of importance in this context, constituting together the dissipation Φ :

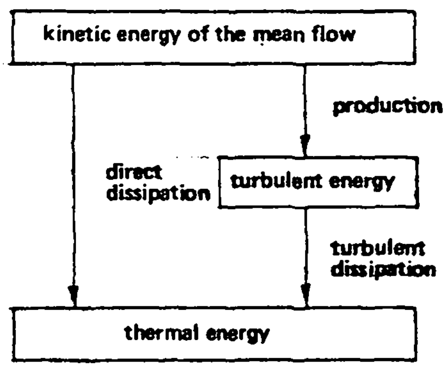


Fig. 1: Conversion of the mechanical energy of the mean motion into heat energy in turbulent pipe flow.

Figure 2 shows what part of the mean dissipation is contained in the direct dissipation $\bar{E}$, as a function of the Reynolds number. If Re = 10^3, E_M constitutes about 49 %, and if Re = 10^8, it makes up only about 9 % of the mean dissipation (Moll, 1985).

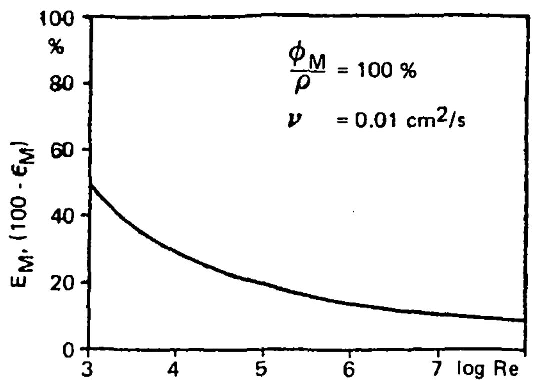


Fig. 2: The part of mean dissipation which is contained in direct dissipation.

Argaman and Kaufman (1970) developed a mathematical expression by means of which flocculation success can be evaluated as the quotient of the particle number in the inlet and the particle number in the outlet of the flocculation process. Their experiments indicate that there exists a certain optimum velocity gradient (G - value) dependent on the duration of flocculation leading to the best flocculation result.

The following expression can be derived as an approximation of the optimum G value on the basis of Argaman and Kaufman results:

$$G_{RMS} = \frac{22000}{T} \left(\sqrt{1 + 0.02\,T} - 1 \right)$$

where G_{RMS} is the root mean square velocity gradient (in one per second) and T is the detention time in the flocculation apparatus (in seconds).

According to literature published to date, it appears that - given the detention time in the flocculation apparatus - an optimum value of G_{RMS} as estimated by means of the equation given above is reached by increasing the G_{RMS} value. Afterwards flocculation success decreases again for further increase of the G_{RMS} value.

Using an equation for Φ_M (Moll, 1985):

$$\Phi_M = (2\rho u_\tau^3 / \kappa R)\left[((2\nu/\kappa u_\tau R) + 1)\cdot \ln(1 + (\kappa u_\tau R / 2\nu)) - 1\right]$$

with
- ρ = density of water
- u_τ = friction velocity
- κ = constant (Kármán)
- R = pipe radius
- ν = kinematic viscosity of water

and the above mentioned equation for G_{RMS} the following expression is obtained:

$$u_M = \sqrt[1.375]{15169\ \frac{R^{0.625}}{T}\ \left(\sqrt{1 + 0.02\,T} - 1\right)}$$

The limit velocity u_M is expressed in cm/s, if the pipe radius R is given in cm and T in s.

In the phosphate elimination plant in Berlin-Tegel the pipe radius is R = 120 cm and the detention time is T = 110 s. Using the above mentioned equation the limit velocity is u_M = 187 cm/s what means that $\dot{V}$ = 8.5 m³/s should not be exceeded.

The pipe which leads the water to the sedimentation tank serves simultaneously as a flocculation unit.

Figure 3 shows the sedimentation tank ① which is fed tangentially at the exterior circumference ② . The water reaches an annular gap ③ , in which it rotates 2 or 3 times and, through openings in the wall ④ , enters the interior part ⑤ where sedimentation will take place. The treated water runs off through a tube ⑥ in the middle of the tank, whereas the flocs settle on the bottom and will be removed as sludge.

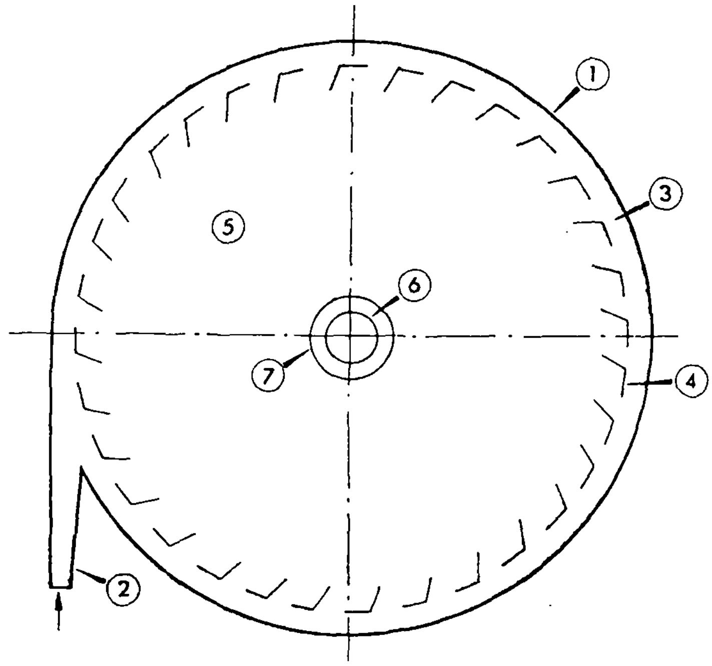


Fig. 3: The groundplan of the sedimentation tank.

This figure, like the two following ones, is only a sketch showing the principle of operation. Details which are not needed for the explanation of the principle, as e.g. the sludge scraper, have been omitted.

Figure 4 shows a section through the settling tank. A specially developed outlet in the middle of the tank consists of two tubes arranged concentrically towards each other. The external tube ⑦ has horizontal slots which are interrupted only by small bars. The water that entered through the slots will flow upwards in a vertical direction between the external and internal tube ⑥ . The water flows into the internal tube at the level of the water surface. This outlet makes it possible that in the water vertical velocity components do not appear in the actual sedimentation part ⑤ .

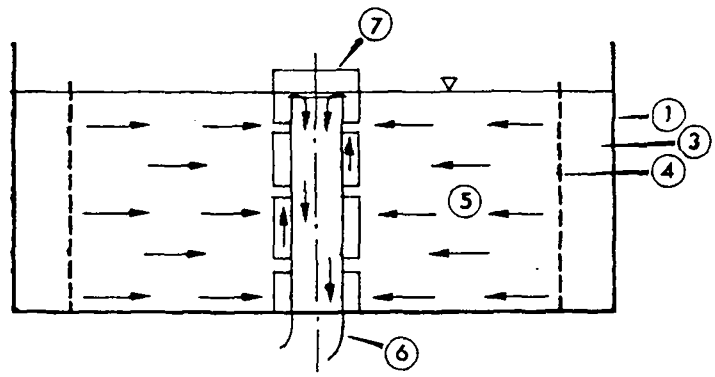


Fig. 4: A section through the settling tank.

Figure 5 shows details of the wall with its openings. It consists of many vanes ⑧ having the task to reduce the high tangential impulse of the water in the annular gap. This is achieved by *reversion* of the direction of rotation. An important feature of the construction of the vanes consists in the fact that they have only trailing edges. These serve to avoid that fibres and the like gather at the vanes.

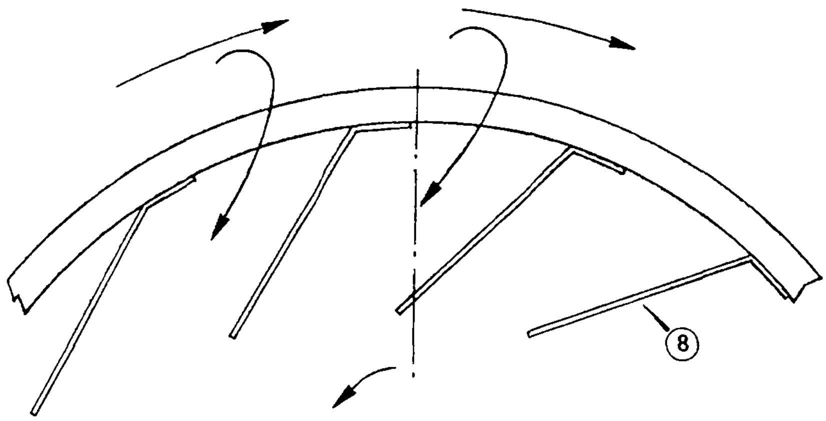


Fig. 5: Guiding vanes

A uniform, stable and slow flow in the sedimentation part of the tank is achieved by this construction.

The rotation of the water in the annular gap ensures that the inlet conditions into the sedimentation part through the vanes are approximately the same for the total height as well as for the total circumference of the sedimentation part.

In conventional circular basins the water flows from the centre to the periphery. Consequently, the radial velocity becomes inceasingly smaller, hence, the flow decelerates.

In the new settling tank with guiding vanes, the water flows from the periphery to the centre. Thus, there is an accelerated flow in the radial and circumferential direction.

Accelerated flows are more stable than decelerated ones. This means that in a circular basin the flow from the periphery to the centre is more stable than the flow from the centre to the periphery.

The slowness is coupled directly with the uniformity and the stability of the flow. If there are no dead water regions the vertical flow area is a maximal one. This means - in connection which the continuity equation - that the velocity becomes a minimum.

In the above mentioned plant in Berlin-Tegel a surface load - related to the total water surface - of about 10 m/h and - related to the surface area of the sedimentation part - of about 13 m/h is achieved.

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SIMULATION GRAPHIQUE DE RESEAUX D'EAU

R. SAUVALLE et J. SARDA

SOCIEDAD GENERAL DE AGUAS DE BARCELONA

ABSTRACT

On décrit la simulation du comportement de réseaux de distribution d'eau potable depuis un système graphique interactif. Le système reflète le réseau de distribution, ses éléments, noeuds, segments et les informations alphanumériques associées aux éléments du réseau; la cartographie de base, formée par le pourtour approximatif des pâtés de maisons; les périmètres administratifs, limites de la municipalité, limites de districts, divisions de la province, etc.; les perimètres hydrauliques entre les différents étages de pression et zones de consommation; et les résultats de la simulation, information alphanumérique qui décrivent le comportement simulé de chaque élément du réseau refleté graphiquement. Le système est dimensionné par un volume de données équivalent au domaine d'influence de la Sociedad General de Aguas de Barcelona, 30.000 Ha. et supporté par un PC-AT avec une configuration matériel formée par 6.272 Kbytes de Ram, dont 5.632 sont utilisés comme Ram-disque à haute vitesse, un co-processeur mathématique 287-turbo et une unité de disque de 80 Mégabytes.

KEYWORDS

Simulation graphique, système graphique interactif, réseau de distribution, simulation de réseaux d'eau, mécanisation graphique, cartographie.

INTRODUCTION

La Sociedad General de Aguas de Barcelona dispose depuis plusieurs années d'un modèle mathématique du réseau de distribution capable de simuler le comportament de toute sorte de réseaux hydrauliques, en partant de ceux les plus élémentaires jusqu'à ceux les plus sophistiqués et compliqués, supporté par un puissant ordinateur.

L'utilisation de ce système de simulation dans des réseaux relativement simples crée le problème d'infrautilisation tant de l'ordinateur comme du propre système et c'est pour cela qu'on a envisagé la nécessité de développer une application qui, supportée par de petits ordinateurs, fût suffisamment utile pour dessiner, projecter et à la fois tracer les réseaux ou sous-réseaux qui, dû à leurs caractéristiques, ne justifiaient pas l'emploi de l'ordinateur central qui en plus s'occupe de la gestion de tout le réseau de distribution.

D'autre part, les départements d'ingénierie et les organismes responsables de la gestion d'approvisionnement et distribution d'eau potable, ont besoin chaque fois plus, de connaître à fond le comportement de leur réseau si réduit soit-il, et des installations hydrauliques; c'est pour cela qu'ils se voient dans l'obligation d'utiliser des éléments qui leur permettent à n'importe quel moment de disposer, non seulement d'une large vision de l'état actuel du réseau, mais également de formuler des hypothèses et de prendre une décision entre différentes alternatives, pour pouvoir faire face aux problèmes que la gestion rationnelle d'une installation présente continuellement.

Dans cette ligne de travail, le développement d'un module de simulation graphique comme instrument d'aide est tout à fait indispensable dans la projection de nouveaux réseaux et dans l'analyse du fonctionnement et des améliorations à réaliser aux réseaux existants.

DESCRIPTION DU SYSTEME

L'objectif est de permettre la simulation du comportement de réseaux de distribution d'eau depuis un système graphique interactif. Le système graphique reflète les données suivantes:

- Le réseau de distribution formé par les éléments physiques du réseau (noeuds, segments linéaux et segments ponctuels: vannes, pompes, etc.) et les informations alphanumériques associées aux éléments du réseau.

- La cartographie de base formée par le pourtour approximatif des pâtés de maisons dans le domaine géographique couvert par la SGAB.

- Périmètres administratifs (limites de la municipalité, etc.), limites entre différents étages de pression et zones de consommation.

- Résultats de la simulation graphique. Les informations alphanumériques qui décrivent le comportement simulé de chaque élément du réseau, ont un reflet graphique.

L'intégration de toutes les informations intéressantes pour la simulation de réseaux dans un unique système graphique permet de disposer des avantages d'un système de cette nature:

- Compréhension immédiate du réseau représenté graphiquement par suite de sa nature et de sa localisation relative dans le milieu urbanistique.

- Utilisation adéquate de niveaux, couleurs et types de ligne.

- Facilité maximum d'interaction.

- Représentation métrique, non simplement topologique.

- Capacité de sortie graphique de n'importe quel sous-ensemble d'information, et à n'importe quelle échelle.

- Facilité d'actualisation.

Le système contemple non seulement la possibilité de simulation, mais encore les processus pour entrer et maintenir toutes les données nécessaires pour la réalisation de ce travail. En suivant la description de la fig. 1., le système de simulation graphique se décompose en 7 grands modules:

1. Introduction de données: Procédé assisté pour l'introduction de données avec reflet graphique (réseau de distribution, base cartographique et limites hydrauliques et administratives); le réseau de distribution étant uniquement un reflet du graphisme et de la situation de chaque élément. Ce réseau s'appelle réseau incomplet.

2. Complétement de données: Procédé interactif pour le complétement de données alphanumériques qui sont associées à chaque élément du réseau. Ce procédé aura comme entrée le réseau incomplet et les données historiques de l'entreprise relatives au réseau. Le résultat final sera une image graphique du réseau que nous appelons réseau stable.

3. Edition du réseau stable: Procédé pour rendre l'image du réseau graphique plus en accord avec la réalité (entrée de nouveaux éléments, élimination d'éléments déjà existants, modifications). Il agit interactivement sur les mêmes fichiers que le réseau stable contient.

4. Extraction du réseau à simuler: Procédé qui fournit le sous-réseau objet de la simulation. Il prend pour entrée le réseau stable. Le résultat de cette extraction s'appelle réseau à simuler.

5. Edition du réseau à simuler: Procédé qui permet à l'opérateur d'introduire interactivement les conditions de la simulation (entrée de nouveaux éléments, élimination d'éléments déjà existants, modifications). Ce maintien se réalise interactivement sur le fichier contenant le réseau à simuler. Le résultat en est un réseau qui répond à toutes les spécifications imposées par l'opérateur.

6. Simulation: Basé sur le système de simulation alphanumérique appelé SIAX. Il prend les données des fichiers contenant le réseau à simuler et les processus dans le mode élu interactivement par l'opérateur et réalise la simulation en laissant les résultats pour une intégration postérieure et une visualisation graphique.

Le programme de simulation alphanumérique est un modèle mathématique qui nous permet de déterminer la distribution de pressions, la valeur des débits, les pertes de charge et les vitesses des éléments d'un réseau modélisé, en simulant le comportement hydraulique du réseau avec des données réelles de celui-ci. Le réseau modélisé est un diagramme schématique du réseau réel, qui décrit les caractéristiques hydrauliques et topologiques du système de distribution d'eau du réseau et qui est formé par un ensemble de noeuds et segments.

Les segments du modèle sont utilisés pour modéliser chacun des éléments hydrauliques qui forment le réseau réel (tuyauteries, pompes, vannes, etc). Ils sont identifiés par un noeud initial et un noeud final qui délimitent le commencement et la fin du segment, et par les caractéristiques propres de l'élément hydraulique qu'ils modélisent. Les noeuds du modèle, qui sont les noeuds initial et final des segments, représentent les points d'interconnexion des tuyauteries, ou les points d'apport ou consommation du réseau. La simulation du réseau demande de trouver un ensemble de solutions pouvant être faites par le système d'équations qui résultent de la formulation mathématique du rapport existant entre les variables indépendantes (données des apports, soit pressions ou débits, et les consommations) et les variables dépendantes ou inconnues (les pressions dans les noeuds et le débit de passage par un segment), en connaissant pour chaque type de segment la fonction qui met en rapport la perte de pression avec le débit.

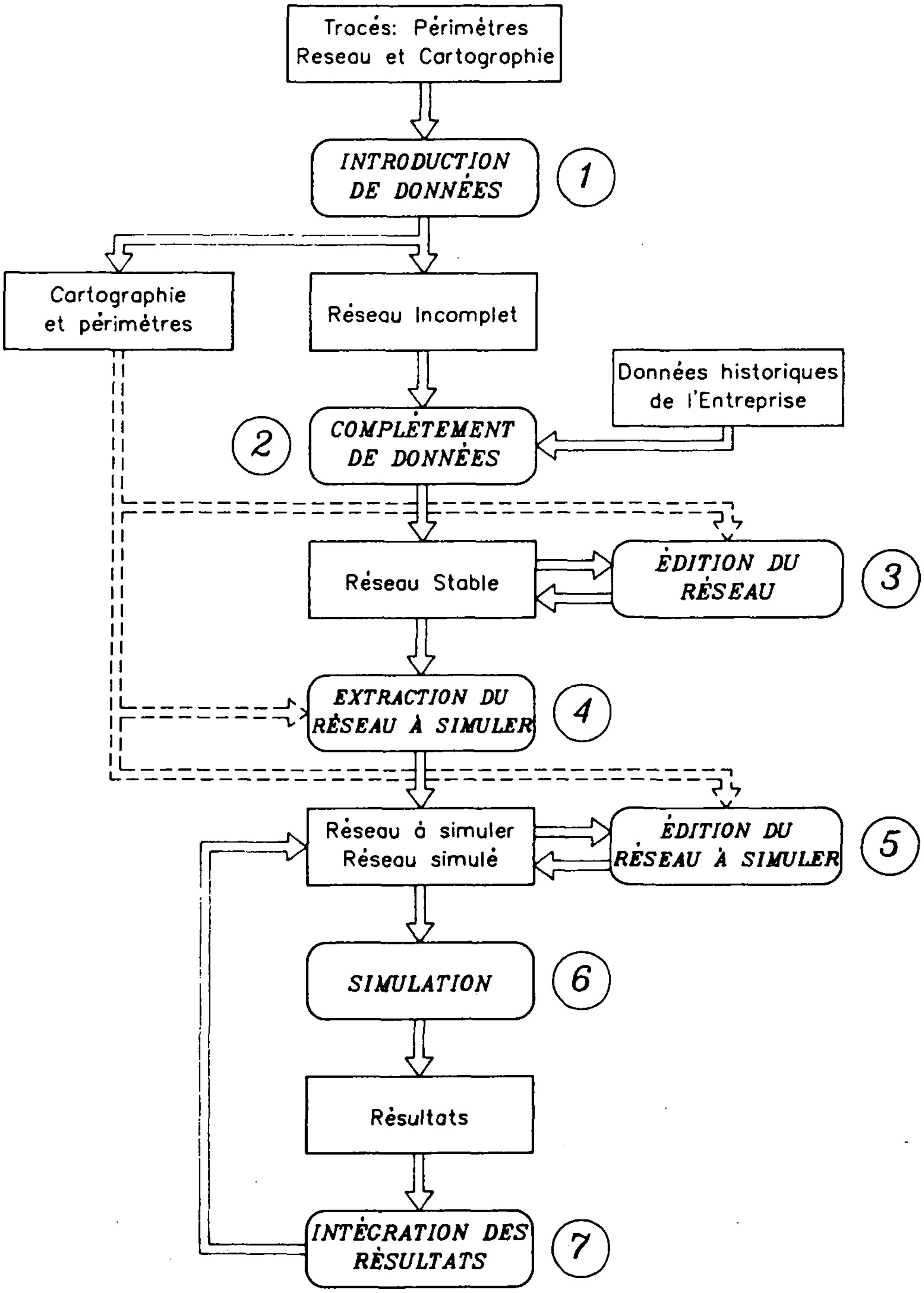

Fig.1. Analyse à primer niveau de l'application.

Actuellement de nouveaux algorithmes permettent de déterminer les pressions et les débits dans des réseaux maillés, en améliorant la convergence dans la recherche de solutions et en réduisant l'occupation de mémoire de l'ordinateur. Les méthodes utilisées principalement sont celle de Hardy-Cross (amélioré), celle de la théorie linéale et celle de Newton-Raphson.

7. Intégration de résultats: Procédé d'intégration au graphisme des résultats alphanumériques de la simulation. Ceci nous permet de consulter simultanément les résultats de la simulation, en même temps que les données qui décrivent le réseau. En arrivant à ce point, l'opérateur peut opter pour modifier les conditions de simulation et d'exécuter de nouveau ce procédé ou bien d'imprimer les résultats intéressants.

CONFIGURATION DU SYSTEME

Afin de supporter l'application développée on a élu une configuration basée le plus possible sur des éléments standard. C'est pour cela que le matériel est composé par un PC-AT de 512 kbytes de mémoire RAM, un processeur 80286-6, deux portes série RS-232, une unité de floppy et une de ruban streamer rapide de 60 Mbytes avec leurs plaques de contrôle correspondantes, ainsi que la plaque de contrôle du moniteur graphique. Il s'agit d'un matériel standard dans un PC de ce type. On lui a incorporé en plus un coprocesseur mathématique 287-Turbo Microway, deux plaques multifonction avec un total de 6 Mbytes de mémoire RAM rapide, en dédiant un bloc de 512 kbytes à l'agrandissement de la mémoire centrale à 640 kbytes, alors que les 5632 kbytes restants sont utilisés comme RAM-DISC à haute vitesse. On y a également incorporé une unité de disque de 80 Mbytes et 28 ms. de temps moyen d'accès.

Le reste du matériel est composé par un moniteur monochrome de 9", un moniteur graphique à haute résolution 1024*768*4, une imprimante, une petite table digitalisatrice DIN-A3 avec un curseur à 4 commandements, dédiée aux travaux d'édition du réseau à simuler et d'édition ponctuelle non massive, une table digitalisatrice DIN-AO avec un curseur à 16 commandements dédiée à l'entrée massive de données graphiques et un traceur DIN-AO de mode duel de 8 plumes.

Pour la mise en application du système on a employé un logiciel spécifique travaillant sous un environnement MS-DOS. Le logiciel de base graphique utilisé est le noyau graphique AUTOCAD avec les extensions ADE II et ADE III. L'application s'est développée avec les langages de programmation Fortran et Basic compilé, en employant les routines d'indexation FABS86M.

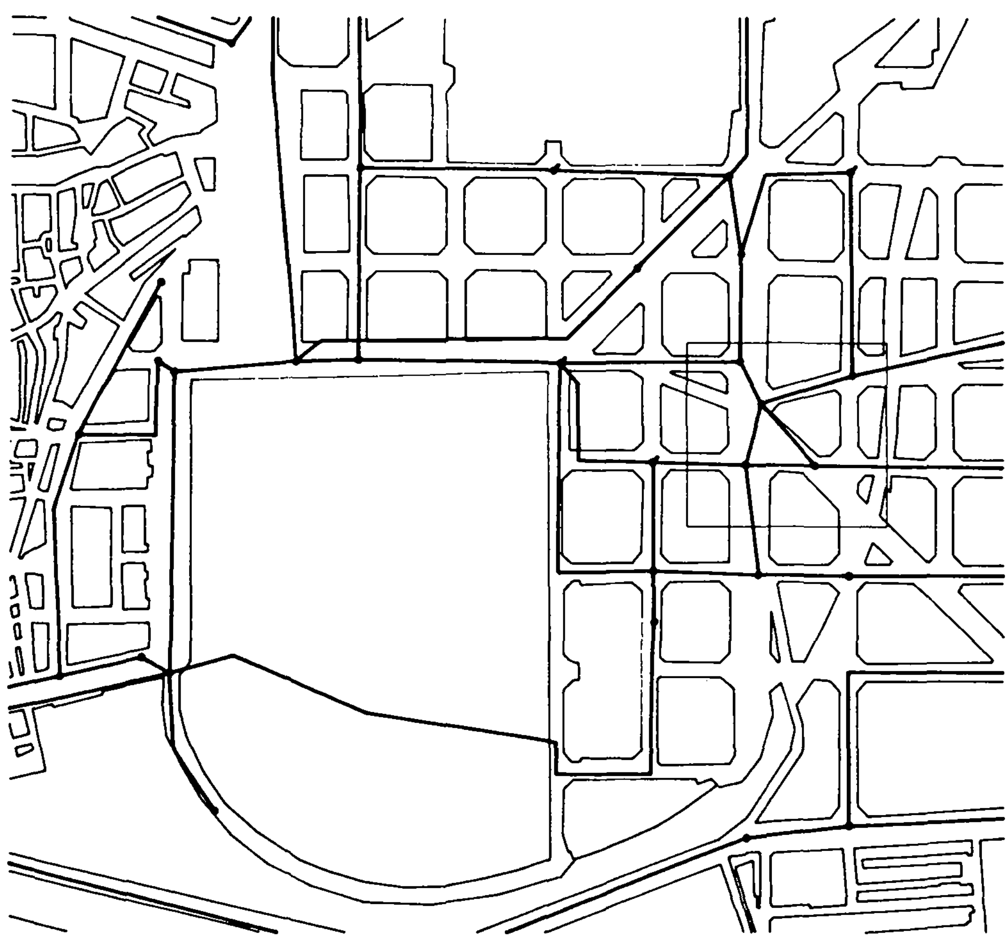

Fig.2. Réseau primaire de distribution.

CONCLUSIONS

Le système développé permet l'étude de sous-réseaux de grandeur moyenne ou petite sans qu'on doive utiliser l'ordinateur central, en obtenant une sortie graphique du réseau simulé, très utile pour faire face à des problèmes sectoriels du réseau général ainsi que pour projeter de futurs renforcements dans des zones saturées.

De même il démontre d'une part la viabilité d'entreprendre des projets graphiques de caractère moyen avec des ordinateurs du type PC, ayant comme conséquence une diminution dans les coûts, tant dans des équipes "Matériel" que de maintien.

D'autre part, il démontre que des entreprises d'approvisionnement d'eau de grandeur moyenne, bien que ne disposant pas d'aucune structure informatique, et ne peuvent opter à de grands systèmes graphiques, généralement très chers, ont la possibilité de réaliser la mécanisation graphique de leur entreprise à un coût bas et avec des prestations complètement suffisantes.

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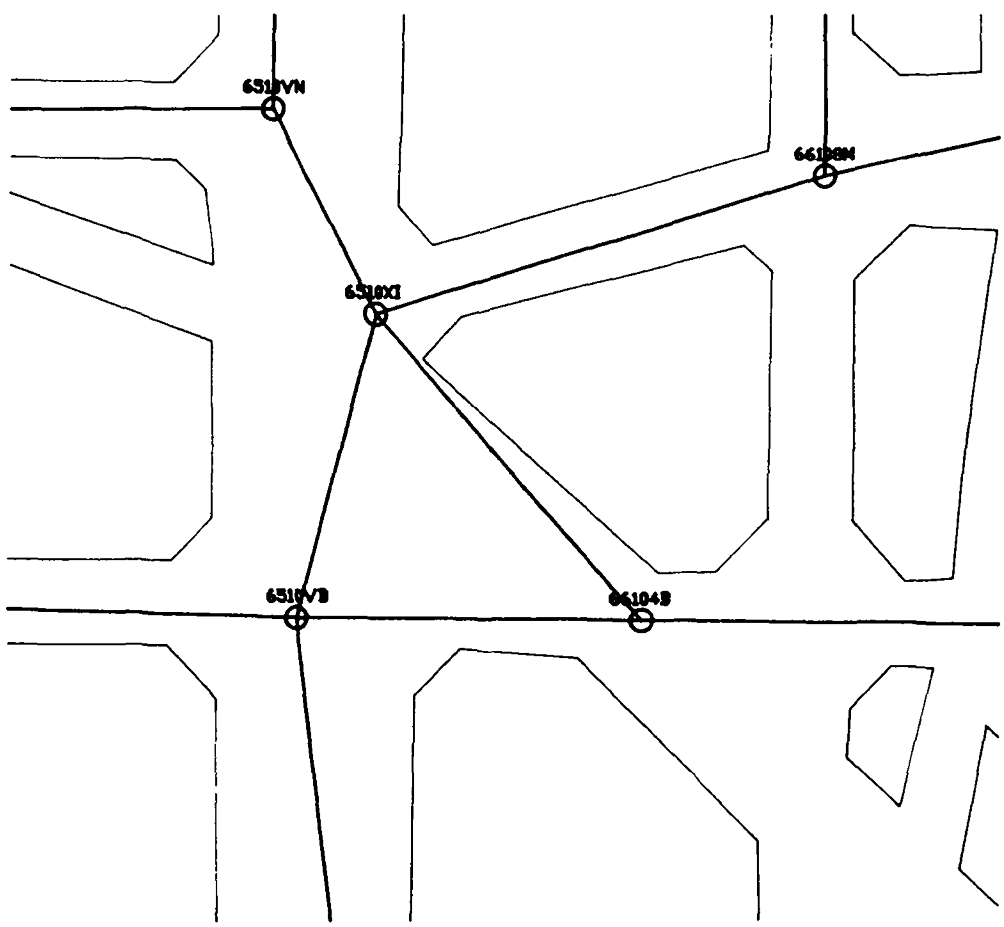

Fig.3. Agrandissement réseau primaire