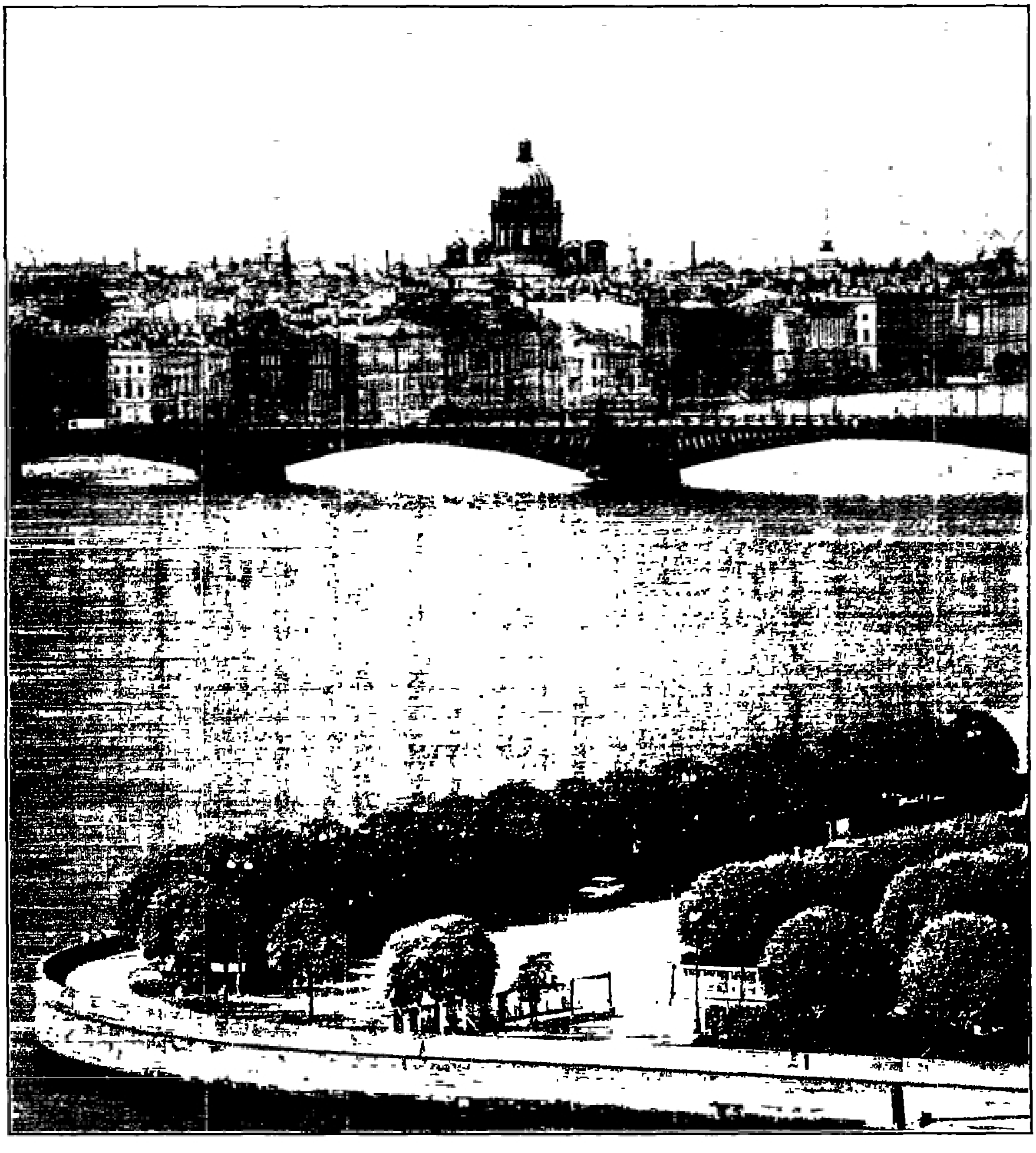
Kymi Water and Environment District

Water Protection Measures for the Neva River Catchment Area to Ensure Water Supply for St. Petersburg

Pre-Feasibility Study



Plancenter Ltd

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SUMMARY

There are technical, aesthetic and even hygienic problems with potable water from St. Petersburg. Taste, odour, turbidity, colour, iron, manganese, aluminium, ammonia, pH balance, organic chlorine compounds and micro-organisms occasionally reach unsuitable levels. Treated water has anyhow fulfilled national GOST norms.

The Neva River is heavily polluted with waste water. The high content of faecal micro-organisms, oil products and nutrients are the greatest deterants to its suitability as raw water. Additionally, storms on Lake Ladoga can significantly increase the concentration of suspended solids. Nevertheless, within a few years the Neva seems to be the only realistic option as the main raw water source for St. Petersburg. It would take a long time before other water alternatives could be used for the production of potable water.

To improve the quality of potable water the following immediate measures are proposed for water treatment plants:

- all water should be treated with adequate amounts of flocculants
- disinfection should be intensified
- treated water should be alkalized

Water treatment capacity should be increased by 450,000 m^3/d, if water consumption cannot be quickly decreased. The raw water to existing water treatment plants is taken from five different intakes two of which sustain water qualities which are occasionally quite poor. These two intakes and/or the treatment plants should be rebuilt at a better location along the river. The direct waste water discharges to the Neva above the intake sites should be diverted and proper waste water treatment plants constructed for them. The effluents from waste water treatment plants should be transferred downstream from the intake sites.

To ensure the raw water quality of St. Petersburg the targets mentioned in the mutual water protection action plan between Finland and the Russian Federation are necessary and urgent. Because of the enormous size of Lake Ladoga, major parts of it are still in fairly good condition. Areas around the mouths of the main rivers and the surroundings of some municipalities and industrial enterprises are however heavily polluted. The shallow southern part of the lake, to which the greatest nutrient loads are directed, is the most eutrophicated. This has a direct relation to the water quality of the Neva.

Within the catchment area of Lake Ladoga the greatest phosphorus point- sources, the Volkhov aluminium plant and Svetogorsk pulp and paper mill, as well as the non-point load from agriculture, are the most urgent priorities in preventing further eutrophication of the lake. Livestock farms are in a key position as well. Savings from fertilizers will benefit agriculture economically. The phosphorus load from Finland is about 4 per cent of that of Lake Ladoga's and point-sources cover only about 10 per cent of that. Therefore, waste water from Finland does not threaten the state of Lake Ladoga.

Investments of about 450 million USD are necessary to reach the targets for water protection within the catchment area of Lake Ladoga. If production could be limited or even some enterprises closed down, these costs could be reduced. To restore the lake's ecological balance to what it was a few decades earlier, more reductions in loads are necessary especially within the agriculture and livestock sector, or significantly more investments should be made in waste water treatment.

If half of the target phosphorus reduction in the water protection action plan is reached, the present eutrophication process could be stopped and the water quality improved at least in some parts of the lake. Water protection measures for acheiving these reductions could be implemented with costs of approximately 150 million USD.

In the long term, water treatment for St. Petersburg should be intensified at least by activated carbon filtration and preferably by ozonation as well. A large raw water reservoir would be the solution for maintianing potable water quality during storms and when the snow melts.

Alternative solutions to improving the potable water quality for St. Petersburg are related to the transfer of cleaner raw water from Lake Ladoga or the upper course of the Vuoksi River. Water quality in Lake Ladoga is not dependent on water protection measures along the Neva and all direct waste water loads could easily be illiminated in the upper Vuoksi. It is possible that waste water effluents do not directly effect the intended intake location in Lake Ladoga either.

The investment costs to bring water quality to the target level will be about 400 million USD if more water is taken from the Neva. If water is transfered from Lake Ladoga the cost will be about 600 million USD and from the Vuoksi 900 mUSD. If a one week raw water reservoir for St. Petersburg is taken from the Neva total investment costs would be close to those for Lake Ladoga.

When additional maintenance costs are taken into account and investments converted to annuity costs, the long term cost effectiveness of Lake Ladoga and Neva River is about the same. Because of the time necessary to construct the water transfer system and possible technical difficulties in construction, the Neva would probably be the most attractive alternative for a period of about 30 years.

Decreasing consumption and leakages would be benefitial. At present per capita water consumption in St. Petersburg is about 540 l/cap/d, which is almost twice as much as in western countries. The more water consumption can be decreased the smaller water treatment and transfer system is needed and the cheaper it is to build and use.

Water for drinking could be delivered separately from water for other purposes. If all inhabitants of St. Petersburg would buy their daily drinking water in bottles (3 l/cap/d), it would cost about 2,700 million USD a year, if the price were equal to Finnish bottle markets. It would be much cheaper for the citizens if the city produced, delivered and sold water. Raw water quality for the production of drinking water should be as good as possible. Natural or artificial groundwater would be the best alternative, but water from the upper Vuoksi or the cleaner parts of Lake Ladoga would be suitable as well.

According to a map examination 15,000 m^3/d (the daily need for drinking and cooking in St. Petersburg) groundwater could easily be taken even from the closest esker, which is located at the shore of Lake Ladoga about 40 km from St. Petersburg. The cost of intake and the transfer system from there to the city border would be about 15 million USD. If water quantity is not sufficient it could be increased by bankfiltration, artificial groundwater or more groundwater transferred from other eskers. The total area of 7 eskers closer than 80 km from St. Petersburg is over 200 km^2. The probable water yield from these eskers would be up to 200,000 m^3/d.

PREFACE

General

Objectives set by the mutual agreement concerning water protection measures between the Finnish Republic and the Russian Federation (Action Plan) are the basic outline for the master plan under preparation. The Neva River Water Protection Master Plan is to form a solid base for water protection action policy in the border areas between Finland and Russia. This pre-feasibility study is a sub-project connected to the elaboration of the master plan in which the optimal water protection measures for the River Neva catchment area will be determined. Based on the findings from different sub-projects, alternative water protection strategies will be elaborated taking into account the future demands for water utilization and protection. Technical implementation of different alternatives will be described and cost estimates made.

Purpose of This Study

The main purpose of this sub-project is to identify needs for water protection and key problems from the point of view of St. Petersburg's water supply. The purpose is further to identify the possibilities to protect existing water sources, to introduce alternative raw water sources and to compare different alternatives.

Project Set-Up

This study is financed by the Kymi Water and Environment District (KWED) and supervised by a Finnish-Russian Steering Group consisting of the following members:

Mr Alexei Frolov	Lenkomekologia, Russia
Ms Olga Snopkovskaya	Lenkomekologia, Russian Project Coordinator
Mr Valery Kurchanov	Health Board of the City of St. Petersburg
Mr Igor Malevanni	Health Board of the Leningrad Region
Mr Sergei Gumen	Vodokanal St. Petersburg, Russia
Mr Dmitry Utrobin	Oblovodokanal, Russia
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Mr Vesa Ranta-Pere	KWED, Finland
Mr Olli Valo	KWED, Finnish Project Coordinator

The work has been carried out by a Finnish Consulting Company, Plancenter Ltd. In its work, Plancenter has been assisted by the officials of the Steering Group, by the Institute of Lake Research, St. Petersburg, Russia and by Water-Eco Ltd, Finland.

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PRESENT WATER SUPPLY SYSTEM OF ST. PETERSBURG

1.1
Water Works of St. Petersburg

1.1.1
General

Supply area

The water supply system of St. Petersburg (Leningrad 1924 - 1991) covers the city and its suburbs. The total number of population served is about 5.85 million inhabitants.

Raw water source

Raw water is mainly taken from the River Neva. Only some of the suburbs (Zestroretsk, Zelenogorsk, Petrodvorets, Krondstadt and Krasnoje Selo) use ground water. In addition, Krondstadt has a plant in which brackish water from the Gulf of Finland is used as a raw water source (Vodokanal, St. Petersburg 1993).

Water supply system

The present water supply system of the city covers five water treatment plants all using Neva water. The plants, listed in order regarding their location along River Neva, are as follows:

- Southern Water Treatment Plant	(SWTP)
- Northern Water Treatment Plant	(NWTP)
- Volkovskaya Water Treatment Plant	(VWTP)
- Main Water Treatment Plant	(MWTP)
- Petrogradskaya Water Treatment Plant	(PWTP)

The administration of the five plants is divided between the Main and the Southern Water Treatment Plants as follows:

- MWTP: itself, PWTP and NWTP
- SWTP: itself and VWTP

1.1.2
Water Consumption

The development of the water supply capacity in the city of St. Petersburg between 1877 - 1987 is presented in Figure 1. Present planned capacity is 3,050,000 m^3/d (521 l/inh/d) but the actual average delivered amount is 3,150,000 m^3/d (543 l/inh/d) /Vodokanal St. Petersburg, 1994/.

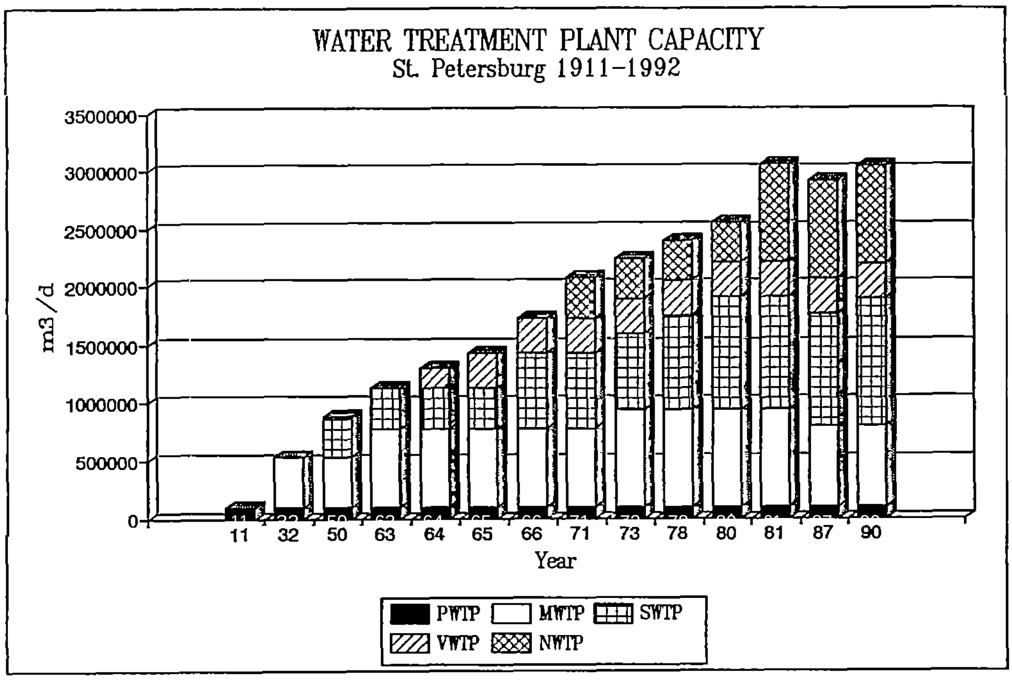

Figure 1. Development of the water supply capacity in St. Petersburg.

Table 1 displays the different capacities of the existing five water treatment plants in St. Petersburg.

Table 1. Capacities and actual pumped amounts (m^3/d) of the water treatment plants of St.Petersburg

Plant	Planned capacity	Delivered amount	Maximum delivered amount
SWTP	1,095,000	1,193,000	1,320,000
NWTP	850,000	837,000	919,000
MWTP	705,000	721,000	793,000
VWTP	300,000	323,000	389,000
PWTP	100,000	75,000	95,000
Total	3,050,000	3,150,000	
l/cap/d	521	543	

According to the national norms, a reserve water supply capacity of 10 % is required but there is none. Instead, some 400,000 m^3/d of capacity is reported lacking.

1.1.3
Existing Plans

Increasing the water supply capacity

Intensive building in St. Petersburg during recent years has led to a growing water demand and overloading of the existing plants. A development program to increase the water supply capacity of the city by 750,000 m^3/d during the years 1987-1991 was prepared in the mid 1980's. Table 2 displays the reported situation of the program in 1993.

Table 2. The reported situation of St. Petersburg water supply development program (1993).

Plant	Capacity m^3/d	Planned year of completion	Real situation in 1993
NWTP	500,000	1989	-
SWTP	250,000	1991	125,000
Total	750,000		125,000

Delays in the developing program has led to lack of sufficient water supply capacity in St. Petersburg.

Decreasing the water consumption

Efforts to cut down water consumption in St. Petersburg have been made. A special water conservation program has been prepared by the water and waste water authorities (Vodokanal) which consists of the following main measures:

- decreasing the amount of leakage
- decreasing the unnecessary water consumption
- installing proper plumbing equipment
- improving the measurement of consumption
- renewing the tariff policy

Implementation of the program between 1990 - 2010 is estimated to achieve a 30 % reduction in water consumption by 2010. The total costs of the program (1990 price level) are 6,000 MSUR (300 MSUR/a).

Clean Water Program

A special Clean Water Program has been recently prepared by Vodokanal. The program is divided into two main sections. The first section deals with all the problems associated with the water supply system of the City as a whole, the second one deals with the strategy to tackle these problems.

1.2
Present Potable Water Quality

The summary of potable water analyses taken from water treatment plants in 1991 - 1993 by Vodokanal is presented in appendix 7. These values have been compared to national norms and the requirements of European Union (EU), which are presented in appendix 1. In appendix 7 there is also results of some samples taken and analysed by Finns in 1992 and 1993.

According to Vodokanal St. Petersburg (1994) the quality of distributed water meet with the national GOST norms. Each of the five main water treatment plants have their own laboratory, in which the quality of both raw and treated water is monitored. In addition to this Vodokanal has its own central laboratory, which controls the water quality of the raw water at intakes and the potable water at treatment plants as well as in distribution system. According to Russian authorities water treatment plants are responsible only for the treated water quality not the quality at consumption points.

In the future the objective of Vodokanal is to reach the WHO water quality recommendations. At present the following substances exceed these recommendations even within the water plants:

- aluminium
- chloroform
- carbon tetrachloride
- colour
- turbidity

Some other water quality parameters which might be improved even in consumption points are listed below:

- taste
- odour
- alkalinity
- pH
- iron
- manganese
- copper
- COD
- aromatic chlorine hydro carbons
- ammonia
- micro-organisms

Turbidity is a problem especially during and after storms in Lake Ladoga. Taste and odour are worst during the melting period in the spring.

COD_{Mn} value, ammonia and alkalinity are not mentioned in the WHO guidelines. The measured COD_{Mn} concentrations are higher than EU requirement (MAC). Colour is quite high as well, which indicates the same potential problems. Aluminium and ammonia concentrations have been a bit higher than EU demands. Mainly they are residues of water treatment chemicals. Alkalinity, hardness and pH level have been a bit low, which increases the risk of corrosion in distribution system.

Because of corrosion iron, manganese and copper concentrations have occasionally been too high in some consumption points. This causes colour faults to laundry and sanitary furniture.

Faecal and total coliform bacteria are not present in treated water at water plants, but it is possible, that micro-organisms can live in distribution system. The present ammonium chlorination process cannot quarantee the microbiological quality of water in consumption points. Besides chlorine is in some cases over dosed in treated water, which increases the content of aromatic chlorine hydro carbons.

1.3
Water Treatment

1.3.1
Southern Water Treatment Plant

Background

After the completion of the second construction phase (1950) the capacity of the plant was 360,000 m^3/d. Since then the plant has been expanded as follows:

- 1966, capacity increment 300,000 m^3/d
- 1980, capacity increment 310,000 m^3/d
- 1990, capacity increment 125,000 m^3/d

Present capacity is 1,095,000 m^3/d. The average amount of water delivered is about 1,193,000 m^3/d and the maximum amount is 1,320,000 m^3/d. The present number of staff at the Southern and Volkovsky treatment plants is together 510 (1.1.1993).

Intakes

Raw water is taken from the River Neva. Raw water enters the plant through two intakes. The first intake (built 1932) is equipped with five pumps, three with the delivery of 11,000 - 14,000 m^3/h and two with 7,800 m^3/h. The second intake (built 1966) is equipped with four pumps (14,400 m^3/h each). The third intake is under construction.

Water is taken from the river through 10 suction pipes with diameters ranging from 1,200 to 1,400 mm. The end of each suction pipe is equipped with an electrically heated strainer to prevent the freezing of the pipe. Both intakes are located at the shore of the River Neva.

Treatment process

The actual treatment process is located in five separate buildings. In two of these buildings chemical flocculation, sedimentation and rapid sand filtration is used for water treatment. The total capacity of these units is 360,000 m^3/d. In the remaining three buildings microsieving and chemical flocculation with contact filtration is used for water treatment. The total capacity of these units is 860,000 m^3/d.

In the rapid sand filtration buildings chemicals are dosed to flocculation channels after which the water is conveyed to sedimentation and further on to filters. Both of these buildings has two sedimentation basins and 16 filters with an area of 96 m^2 each. The total filtration area is 3,072 m^2 meaning that the surface load varies from 6 to 8 m/h (max 10 m/h).

In the contact filtration buildings raw water is pre-treated in microsieves (gap size 0,5 · 0,5 mm^2). Chemicals are dosed straight before filtration. Two of the buildings consist of eight microsieves and 24 contact filters each with an area of 105 m^2 (total filtration area 5,040 m^2). The third building consists of eight mircosieves and 28 contact filters each with the area of 89 m^2. The total filtration area in the third building is 2,492 m^2 while the total filtration area of all contact filters is 7,352 m^2. The surface loads used in contact filtration vary between 5 - 6 m/h.

Most of the time the plant exceeds its planned capacity. The filters are washed three times a day during spring and autumn, once during winter. A treatment unit for filter washing water is under construction.

The treated waters are stored in nine separate fresh water reservoirs having a total volume of 123,000 m^3. Water is pumped to the distribution network through four pressure lifting stations equipped with 21 pumps each with the delivery from 5,000 to 5,100 m^3/h.

Chemicals

Chlorine and ammonia are used for disinfection (chloramine disinfection). These chemicals are dosed to the inlet chambers located inside the treatment buildings.

Aluminum sulphate is used as a flocculant. It is dosed into a dividing chanel. It is brought to the plant either in a solid form or in a liquidized form in tanks. Aluminum dosage is controlled automatically by monitoring the difference between the conductivity of the incoming and treated water.

The pH of the Neva water varies usually from 7.0 to 7.7. Aluminum sulphate dosing drops the pH which in the distributed water should be, according to norms, at least 6.5. The operator decides, according to the raw water quality, whether chemicals should be dosed to all the water or only to a certain part of it. Also in case all raw water requires chemical dosing the operator has to increase the pH by dosing soda (Na_2CO_3).

Polyacrylamide is used during the cold season as a coagulant aid in rapid filtration. In addition, potassium permanganate is occasionally used during spring time to prevent odour problems.

Average dosage values of different chemicals are as follows:

-	aluminum sulphate	6.3 mgAl_2O_3/l
	(equivalent to 39 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$)	
-	chlorine	2.54 mg/l
-	polyacrylamide	2.7 mg/l
-	soda	10 mg/l
-	potassium permanganate	0.5 mg/l
-	ammonia	0.36 mg/l

Treatment efficiency

According to Vodokanal St. Petersburg the treated water quality complies with the valid national norms.

Key problems

The people of SWTP have listed the following main problems at the plant:

- extensions at the site are impossible.
- the volume of treated water reservoirs is too small.
- during seven months the temperature of raw water is low affecting problems to chemical dosage.
- during storms (usually during November and December) fine suspended solids concentration in raw water is high and most of it can not be captured by filters; quick clogging of filters, because of coarser suspended solids.
- too low pH and alkality of potable water, when the temperature of the water is low.
- poor quality of coagulant chemicals and weak efficiency, while the temperature of the water is low.
- lack of analytical equipment and automation.

- bad functioning of valves.

Some of the sewage discharge pipes for untreated waste water of the city are located just upstream of the plant. This, of course, effects the quality of the raw water taken inside the plant for treatment. In addition, a disadvantageous water intake location in the curve of the river causes direct migration of solids from the river water into the plant process.

There are especially fine suspended solids in the water during storms (especially in November - December). It is so difficult to separate them from the water that most of it goes throw the filtering units.

1.3.2 Northern Water Treatment Plant

Background

The plant wass originally founded in 1971. The original planned capacity of 350,000 m^3/d has been expanded as follows:

- 1981, capacity increment 500,000 m^3/d

The present (1.1.1993) capacity is 850,000 m^3/d. The present average pumping rate to consumption was 837,000 m^3/d and the maximum daily pumping rate 919,000 m^3/d.

Intakes

Raw water is taken from the River Neva through six suction pipes with diameters of 1,400 mm. The end of each suction pipe is equipped with a electrically heated strainer. The intake (built in 1990) is equipped with six pumps, four with the delivery of 21,200 m^3/h and two with the delivery of 12,300 m^3/h.

Treatment process

The actual treatment process consists of microsieving and chemical flocculation simultaneously with the filtration. The first building consist of eight microsieves and 32 contact filters each with an area of 105 m^2. The second building consists of 16 mircosieves and 48 contact filters each with an area of 105 m^2. The total filtration area is 8,400 m^2 and the average surface load about 5 m/h.

The treated waters are stored in seven separate fresh water reservoirs wih a total volume of 155,000 m^3. Water is pumped to the distribution network through a pressure lifting station equipped with 13 pumps two with the delivery of 2,700, seven with 5,820 m^3/h and four with 6,500 m^3/h.

Chemicals

Polyacrylamide and potassium permanganate is not used at the plant. Otherwise the used chemicals are the same than in SWTP.

Average dosages of different chemicals are as follows:

-	aluminum sulphate	5.9 mgAl_2O_3/l
	(equivalent to 37 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$)	
-	chlorine	2.59 mg/l
-	soda	10 mg/l
-	ammonia	0.32 mg/l

Treatment efficiency

According to Vodokanal St. Petersburg the treated water quality complies with the valid national norms.

Key problems

Similar to those in SWTP.

1.3.3

Main Water Treatment Plant

Background

The plant was originally founded in 1932. The original planned capacity of 440,000 m^3/d has been expanded as follows:

- 1963, capacity increment 240,000 m^3/d
- 1973, capacity increment 165,000 m^3/d

In 1987 the capacity was decreased by 140,000 m^3/d hence the present (1.1.1993) capacity is 705,000 m^3/d. The present average pumping rate to consumption is 721,000 m^3/d and the maximum daily pumping 793,000 m^3/d. The present number of staff at the Main, Petrogradsky and Northern plants together is 593 (1.1.1993).

Intakes

Raw water is taken from the River Neva through ten suction pipes with diameters of 1,200 mm (8 pcs) and 1,400 mm (2 pcs) and three intakes. The intakes are equipped with 14 pumps two with the delivery of 2,500 m^3/h, ten with 5,000 m^3/h and two with 11,500 m^3/h.

Treatment process

The actual treatment process is located in three separate buildings. In one of these buildings chemical flocculation, sedimentation and rapid sand filtration is used for water treatment. The total capacity of this unit is 300,000 m^3/d. In the remaining two buildings microsieving and chemical flocculation with contact filtration is used for water treatment. The total capacity of these units is 405,000 m^3/d.

The rapid sand filtration building consists of eight sedimentation basins and 24 filters with an area of 108 m^2 each. The total filtration area is 2,595 m^2 meaning that the surface load varies from 6 to 8 m/h (max 10 m/h).

In the contact filtration buildings raw water is pre-treated in microsieves (gap size 0,5 · 0,5 mm^2). Chemicals are dosed straight before filtration. These buildings consist of 15 microsieves and 40 contact filters 24 with the area of 78 m^2 and 16 with 87 m^2 (total filtration area 3,264 m^2).

The treated waters are stored in reservoirs having a total volume of 111,000 m^3 (1.1.1993). Water is pumped to the distribution network through five pressure lifting stations equipped with 18 pumps two with the delivery of 2,700 m^3/h, one with 3,000 m^3/h and 15 with 3,600 m^3/h.

Chemicals

Polyacrylamide and potassium permanganate is not used at the plant. Otherwise the chemicals used are the same as in SWTP.

Average dosages of different chemicals are as follows:

-	aluminum sulphate	6.3 mgAl_2O_3/l
	(equivalent to 39 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$)	
-	chlorine	2.62 mg/l
-	soda	10 mg/l
-	ammonia	0.36 mg/l

Treatment efficiency

According to Vodokanal St. Petersburg the treated water quality complies with the valid national norms.

Key problems

The plant is in need of renovation otherwise the key problems are similar to those in SWTP.

1.3.4
Volkovsky Water Treatment Plant

Background

The plant was originally founded in 1964. The original planned capacity of 175,000 m^3/d has been expanded as follows:

- 1965, capacity increment 125,000 m^3/d

Present (1.1.1993) capacity is 300,000 m^3/d. The present average pumping rate to consumption is 323,000 m^3/d and the maximum daily pumping rate 389,000 m^3/d.

Intakes

Raw water is taken from the River Neva through two suction pipes with diameters of 1,200 mm. The intake is equipped with four pumps with the deliveries varying from 11,000 m^3/h to 14,000 m^3/h. The distance between the intake and the actual plant is about 5 km.

Treatment process

The actual treatment process consists of microsieving and contact filtration. The treatment process consist of seven microsieves and 32 contact filters each with the area of 90 m^2. The total filtration area is 2,880 m^2 and the average surface load about 5 m/h.

The treated waters are stored in five separate fresh water reservoirs having a total volume of 65,000 m^3. Water is pumped to the distribution network through two pressure lifting station equipped with eight pumps one with the delivery of 2,500 m^3/h, two with 3,200 m^3/h and five with 3,600 m^3/h.

Chemicals

Polyacrylamide and potassium permanganate is not used at the plant. Otherwise the chemicals used are the same as in SWTP.

Average dosages of different chemicals are as follows:

-	aluminum sulphate (equivalent to 36 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$)	6.0 mgAl_2O_3/l
-	chlorine	2.64 mg/l
-	soda	10 mg/l
-	ammonia	0.3 mg/l

Treatment efficiency

According to Vodokanal St. Petersburg the treated water quality does comply with the valid national GOST norms.

Key problems

The problems are similar to those in SWTP.

1.3.5

Petrogradsky Water Treatment Plant

Background

The plant was originally founded in 1911 and the original planned capacity is 100,000 m^3/d. The present average pumping rate to consumption is about 75,000 m^3/d and the maximum daily pumping rate 95,000 m^3/d.

Intake

Raw water is taken from the River Neva through a tributary. Raw water is taken trough two intakes equipped with two suction pipes (1,050 and 1,200 mm) and with four pumps with the deliveries varying from 1,000 m^3/h to 3,000 m^3/h.

Treatment process

The actual treatment process consists of chemical flocculation, sedimentation and rapid sand filtration. The treatment process consist of 53 rapid sand filters each with the area of 12.6 m^2. The total filtration area is 6,678 m^2.

The treated waters are stored in one fresh water reservoir with the total volume of 12,000 m^3. Water is pumped to the distribution network through one pressure lifting station equipped with six pumps one with the delivery of 1,080 m^3/h, one with 1,250 m^3/h, one with 2,700 m^3/h and three with 3,600 m^3/h.

Chemicals

Polyacrylamide, potassium permanganate and soda is not used at the plant. Otherwise, the chemicals used are the same as in SWTP.

Average dosages of different chemicals are as follows:

-	aluminum sulphate	6.3 mgAl_2O_3/l
	(equivalent to 39 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$)	
-	chlorine	2.55 mg/l
-	ammonia	0.31 mg/l

Treatment efficiency

According to Vodokanal St. Petersburg the treated water quality does comply with the valid national GOST norms.

Key problems

The plant will be closed immediately, but there should be enough capacity at the other plants.

1.4
Water Distribution System

In 1989, the amount of water pumped from the five water treatment plants to the distribution system was 1,106,263,000 m^3 (3,030,000 m^3/d). The amount of sold water was 915,844,000 m^3/a (2,509,000 m^3/d, 83 %). The remaining 17 % (1.4 l/inh/km) was lost mainly due to leakage. These figures are only estimations due to the tariff policy of determining household water consumption by the number of consumers. The reported amount of sold water is divided between different consumer groups as follows:

households:	998,000 m^3/d (40 %) (200 l/inh/d)
service:	851,000 m^3/d (34 %)
industry:	660,000 m^3/d (26 %)

The water distribution system of St.Petersburg covers the city and the suburbs. In the following some key figures of the network is given:

- total length of water distribution pipelines (1.1.1991) was 4,303 km of which 718 km (17 %) is more than 50 years old. The most common pipe materials are:
  - Cast iron (over 50 %)
  - Steel (almost 20 %)
  - Reinforced concrete (almost 4%)
- almost 1,700 pipeline damages appear annually.
- 500 pressure monitoring points.
- 8 main pressure lifting stations.
- 84 areal pressure lifting stations serving buildings with nine floors or more.
- serves 3,200 industrial enterprises of which 75 % are equipped with water meters.
- 55 fresh water tanks, V_{tot}=721,000 m^3.

Operation and maintenance of the network is the responsibility of an enterprise called PEVS. This enterprise is divided into seven local units and four repair and emergency units.

2
PRESENT STATE OF LAKE LADOGA

2.1
The Neva River Catchment Area

The total catchment area of the River Neva is 286,000 km^2 including the area covered with lakes. Neva River itself is relatively short, 74 km, and its direct catchment area is only about 5,000 km^2 (Russian Research Institute for Agricultural Microbiology 1993). The catchment area of Lake Ladoga represents the remaining 281,000 km^2. The area is located in the territory of Russia and Finland, and includes four secondary watersheds: the area of Lake Ladoga itself and drainage area of a number of small rivers discharging into Lake Ladoga (altogether 55,000 km^2), the watersheds of Lake Onega - the Svir (80,200 km^2), Lake Ilmen - the Volkhov (77,300 km^2) and Lake Saimaa - the Vuoksi (68,500 km^2) (see Figure 2).

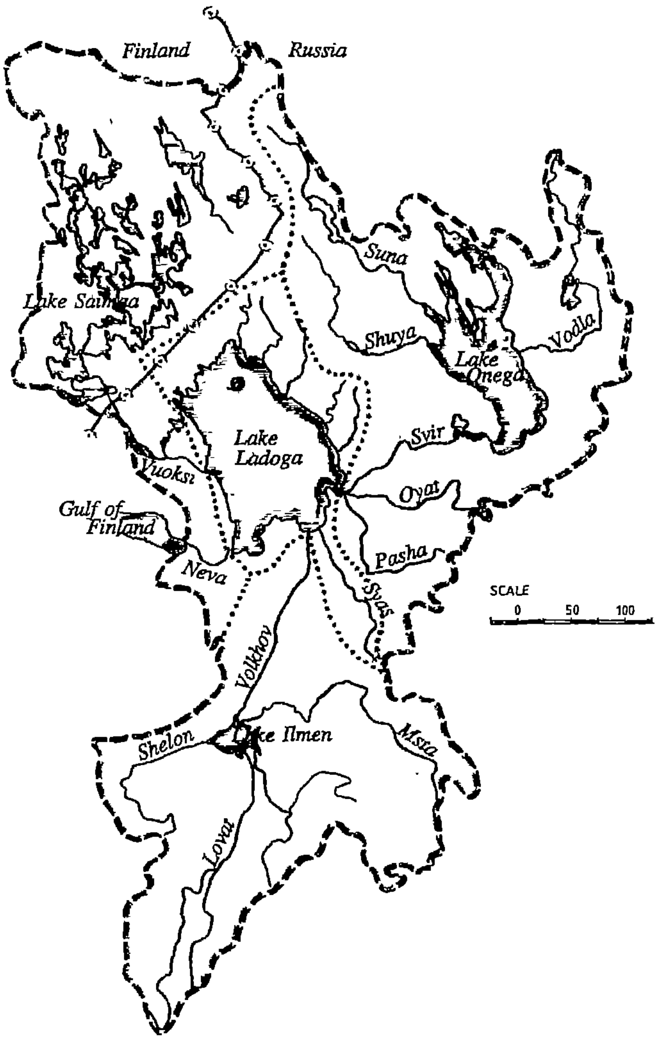

Figure 2. River Neva catchment area

2.2
General Dimensions of Lake Ladoga

Lake Ladoga is the largest lake in Europe. It covers the area of 18,130 km^2 out of which 460 km^2 is occupied by islands. Ladoga is about 3.5 m above sea level. Since the beginning of the 1950's the water level of Lake Ladoga has been regulated. The lake is open and deep. Its volume is 908 km^3 and its average depth 51.0 m and maximum depth 230 m (in north-western part of the lake). The southern part of the lake has an average depth of only 13 m (see Figure 3, Table 3 and Figure 4).

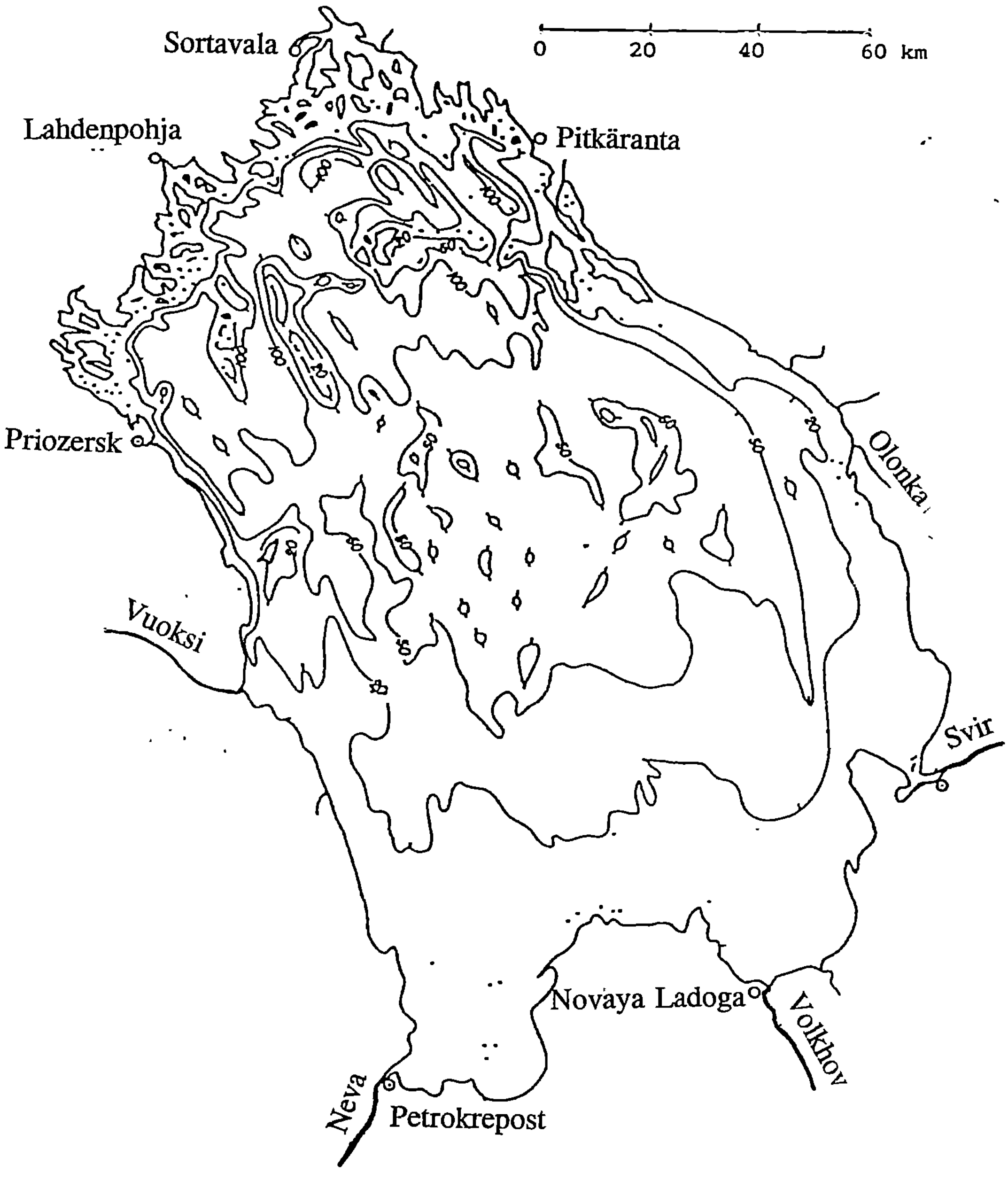

Figure 3. Bathymetric map of Lake Ladoga

Table 3. Properties of depth zones (Institute for Lake Research, Russia)

Zone	Area km^2	Mean depth m	Total depth range m	Volume km^3
Littoral	3,700	9	< 15	30
Slope	5,300	30	15-52	158
Profundal	5,800	66	52-89	382
Ultra-profundal	3,000	113	> 89	338
Sum / mean	17,800	52	0-230	908

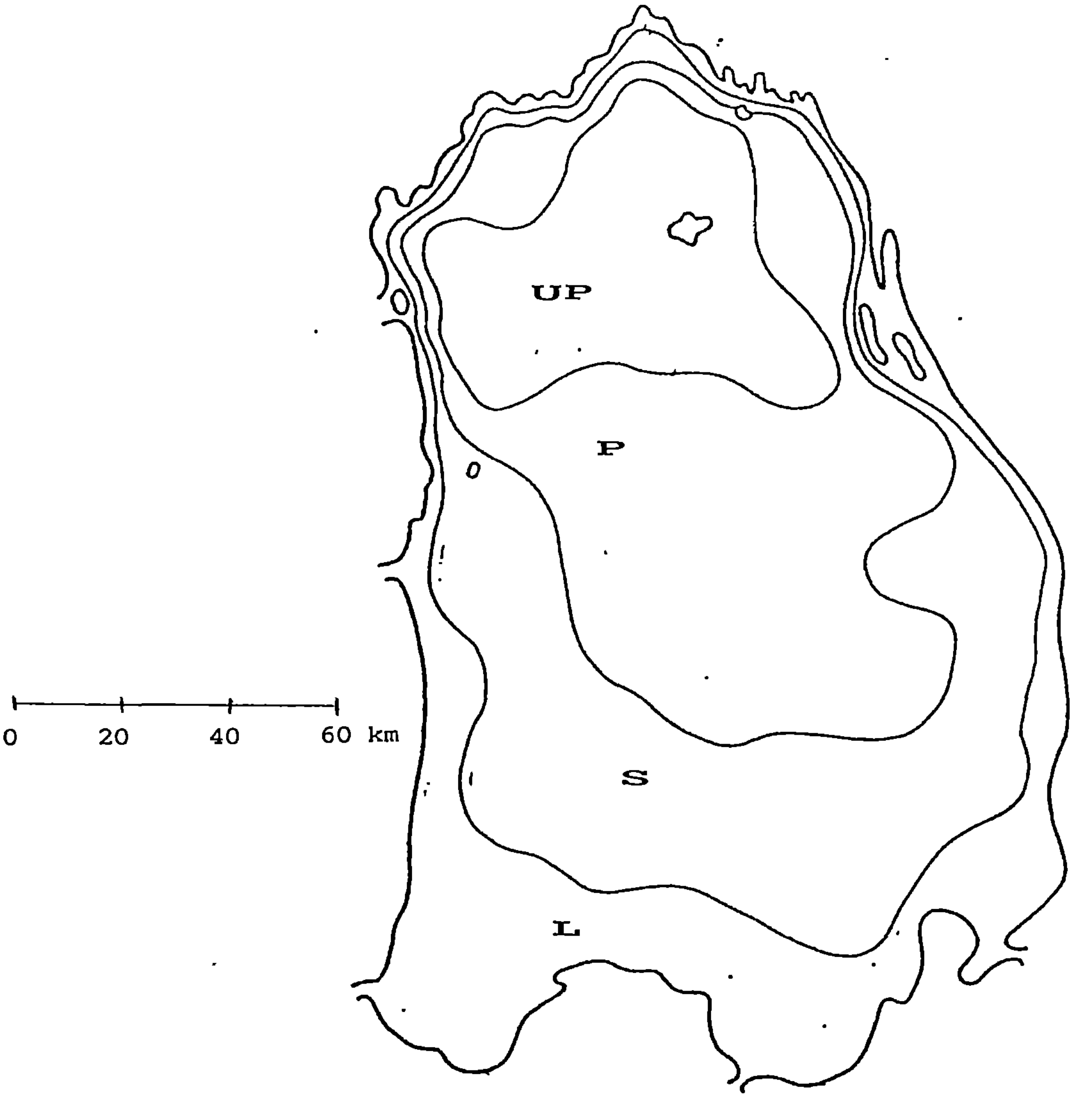

Figure 4. Depth zones of Lake Ladoga (L = Littoral, S = Slope, P = Profundal, UP = Ultra-Profundal)

2.3
Hydrological Regime

2.3.1
Water Balance

River discharge (86 %) and atmospheric precipitation (14 %) are the principal inflow components of the water balance, while the outflow elements consist of the discharge into the River Neva (92 %) and evaporation (8 %) into the atmosphere (Institute for Lake Research 1993). The largest rivers draining to Lake Ladoga are the Vuoksi, the Svir, the Volkhov, the Syas, the Pasha, the Oyat and the Olonka. The first three provide 86 % of the total inflow to the lake. The mean discharge of River Svir is 790 m^3/s, River Volkhov 590 m^3/s and River Vuoksi 617 m^3/s. The mean flow of River Neva is 2600 m^3/s.

Water renewal in Lake Ladoga is slow The coefficient of water exchange is about 0.08, and the lake system is highly conservative. Retention time in the lake is approximately 11.5 years.

2.3.2
Thermal Regime

The period of ice cover extends from November till March (Institute for Lake Research 1993). In the spring the deep northern part of the lake warms up slowly whereas the shallow southern parts warm relatively rapidly (Filatov & Heinonen 1990). The thermal bar divide the nearshore thermally active region from the offshore thermally inert one. The horizontal thermal bar exists in the lake in the period of spring warming (from the beginning of May) and autumn cooling (from the beginning of November) until the end of these periods. The horizontal thermal bar front stretches along the shore line and gradually shifts to the deep water area. The thermal bar divides the lake into two areas whose physical and chemical properties differ sharply from each other. The biggest difference (up to 20 °C) in water temperature of the upper layer is registered during the beginning of hydrological summer. With the thermal bar vanished, some of the dense water with its top over deep water area develops in the lake, and direct thermal stratification with a temperature discontinuity layer over the entire water body reaches a steady state (Institute for Lake Research 1993).

2.3.3
Currents

Currents are of complex character due to large water area and considerable inhomogeneity of the bottom relief. Close to the river outlets the density of water is slightly different from the water in the lake, which tends to slow the mixing of different water masses. These density currents are represented in streams by the shoreline. During the ice-free period the power caused by the circulation of earth is significant and causes counterclockwise circulation of the water mass. Macrovortexes caused by the wind occur most visibly in the northern deep part of the lake (Institute for Lake Research 1993).

Climatic circulation, plotted with the use of 3-D hydrodynamic discreet model (Astrakhantsec et al 1988, ref. Institute for Lake Research 1993) visually reflects the general movement of water masses during the ice-free period in case of low wind velocities (see Figure 5).

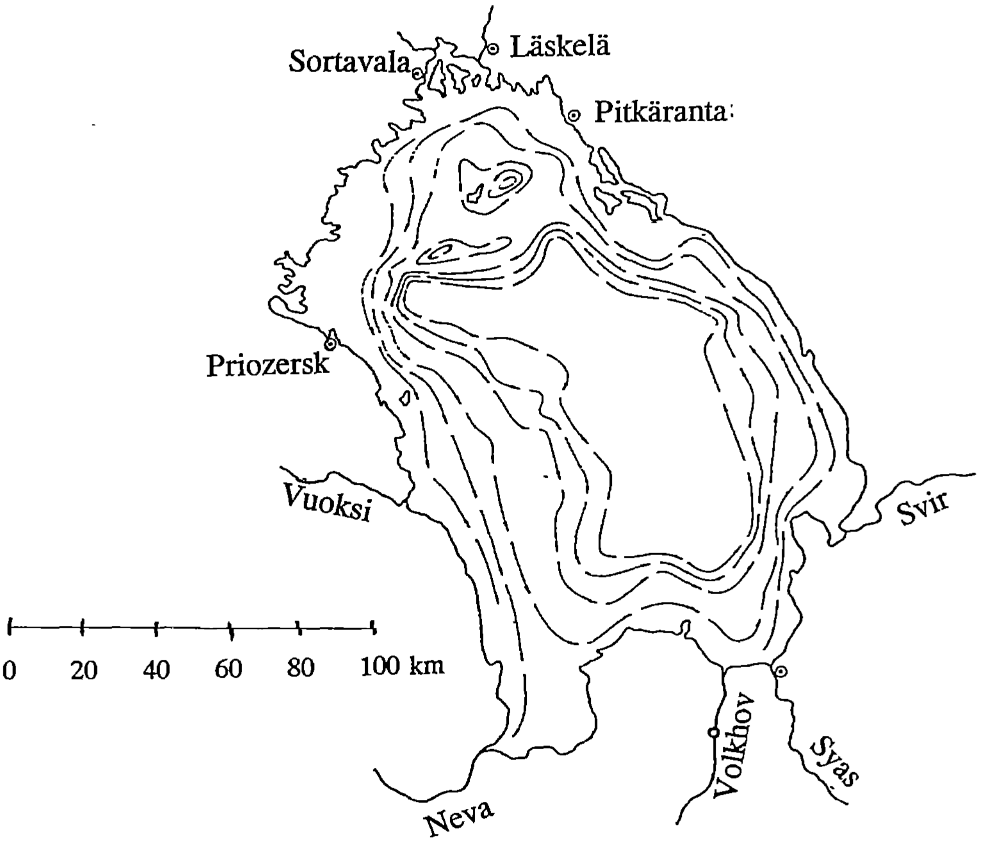

Figure 5. Water mass circulation in Lake Ladoga during ice-free periods (Institute for Lake Research).

Shoreline density currents provide transit transport of water from River Svir and especially from River Volkhov directly to the source of River Neva in the period of ice cover. During ice free periods transit from River Vuoksi is most probable. (Krjuchkov ref. Institute for Lake Research 1993)

The field data on daily variations of electrical conductivity in the River Neva indicate that there is a certain transport of the Volkhov, Syas and Vuoksi River's water to the River Neva under the effect of density currents within the annual cycle. Density current based river water transit in Lake Ladoga is quantitatively most important during the period of ice cover. The data on the transport of the Vuoksi's waters into the Neva indicate that there is a powerful water transport along the western shore of Ladoga (Institute for Lake Research 1993).

2.4
Chemical Composition of the Water

2.4.1
Phosphorus

Anthropogenic eutrophication of Lake Ladoga caused by increased total phosphorus concentration have been noticed since the early 1960's (Viljanen & Drabkova 1992).

At the end of th 1970's the annual average concentration of total phosphorus was 27 μg/l, the range being 8-60 μg/l. In the Bay of Volkhov the highest total phosphorus concentration was 300 μg/l. The annual variations of total phosphorus concentration were rather small (Sabylina 1990). The annual average total phosphorus concentrations from 1976-1989 are presented in Figure 6.

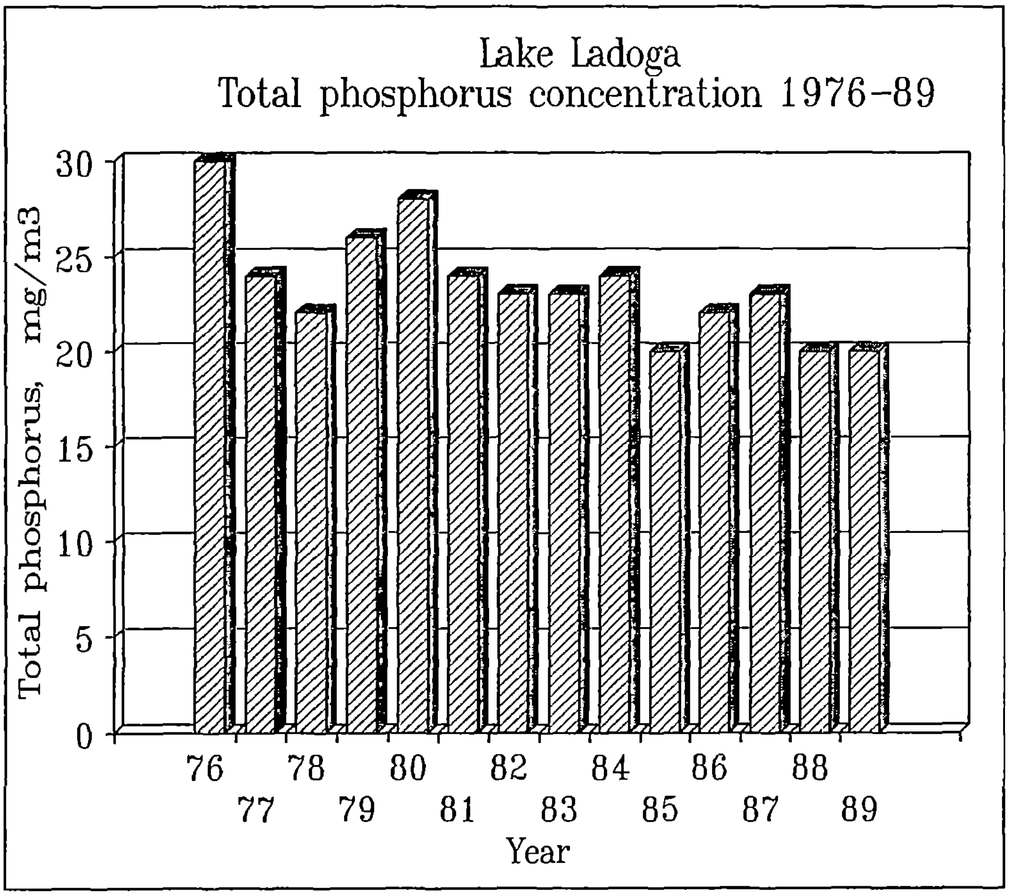

Figure 6. Annual average total phosphorus concentration in Lake Ladoga 1976-1989 (source of information: Institute for Lake Research).

The inorganic phosphorus (phosphate phosphorus) annual average concentration was from 1976-1979 12 μg/l with a concentration four times higher compared to 1959-1962. In most parts of the lake the values varied from 1 to 43 μg/l. In the Bay of Volkhov in the winter the concentration of inorganic phosphorus was 250-350 μg/l. The seasonal variations in inorganic phosphorus can be clearly observed: in winter and in spring the average concentration is 13-15 μg/l, whereas the summer concentrations are about one half of the spring values. During the summer stagnation phytoplankton uses almost all inorganic phosphorus in the trophogenic layer, whereas in the hypolimnion of deep areas the concentrations of inorganic phosphorus remain close to the values measured in spring (Sabylina 1990).

The River Volkhov, with an aluminium producing plant located near the mouth of the river, has very high concentration of phosphorus compounds in its water. Volkhov's aluminium producing plant is the biggest point-source polluter of the lake (Institute for Lake Research 1993). According to study of the local distribution of phosphorus carried out by the Lake Institute of the Science Academy of CCCP in 1984-1985, the concentrations of total phosphorus in the Bay of Volkhov decreased after the water protection measures were imposed at the Volkhov aluminium factory by 4-5 μg/l until 1984-1985 as compared with values measured in 1976-1981 (Sabylina 1990).

According to studies on the average distribution of total phosphorus in Lake Ladoga the average concentrations of total phosphorus had decreased to a level of 20 μg/l at the end of 1990 (Sabylina 1990). In august 1993 the total phosphorus concentrations ranged from 15 μg/l to 29 μg/l on average of sampling depths (Niinioja et al 1993).

2.4.2
Nitrogen

The amount of nitrogen compounds discharged into the lake from the watershed is 10-16 times greater than that of phosphorus. Total nitrogen discharge from the watershed via seven main tributaries amounts to 60,000-69,000 t/a. The Volkhov's share makes up to 31 - 42 %, the Svir and Vuoksi River range from 19-36 % each in the total annual discharge (Institute for Lake Research 1993).

The major form of inorganic nitrogen in Lake Ladoga is nitrate nitrogen. According to Raspletina (1982 ref. Sabylina 1990) the annual average nitrate concentration increased from 150 μg/l to 250 μg/l between 1959-1962 and 1976-1981. In the summer of 1990 the average concentration of nitrate nitrogen was 180 μg/l, which is lower than values observed during period 1976-1981. Minimum concentrations, 100-130 μg/l, were observed in the River Svir, the Bay of Volkhov, and the Bay of Neva, where phytoplankton uses nitrate nitrogen effectively (Sabylina 1990).

At the end of the 1970's the average concentration of total nitrogen was 650 μg/l, the range being 380-2,100 μg/l. The highest values were observed in the Bay of Volkhov. In the summer of 1990 the total nitrogen concentration was estimated to be around 720 μg/l (Sabylina 1990).

In august 1993 total nitrogen concentrations ranged from 620 μg/l to 690 μg/l as an average from surface to bottom (Niinioja et al 1993).

2.4.3
Oxygen

Oxygen deficits have been observed in the hypolimnion (Trebukova & Kulish 1992 ref. Niinioja et al 1993). Noticeable changes have taken place in the concentration of dissolved oxygen since early 1960's. In deep waters the oxygen concentratiosn have been reduced in winter even near the surface (Viljanen & Drabkova 1992).

In august 1993 the oxygen regime in the main part of the lake was fairly good. In most areas the oxygen concentrations varied from 9.0 mg/l to 13.0 mg/l in the sampling depths. The oxygen saturation ranged from 81 % to 107 % in different areas. However, evidences of a waste water load influencing oxygen consumption were observed. Oxygen depletion was observed near Pitkaranta and in Volkhov Bay (Niiniranta et al 1993).

2.4.4
Organic Matter

In august 1993 the average colour values of the whole water column varied from pelagial 28 mg Pt/l to south eastern average value of 39 mg Pt/l. The average COD_{Mn} value for the whole lake was 8.5 mg O_2/l (Niiniranta et al 1993).

The concentration of oil products in the lake's tributaries and in the Neva is mainly within maximum permissible concentration limits, except for the Neva's mouth, where concentrations of oil products were 0.057 mg/l in July, 1992. Concentrations of dissolved oil products, considerably exceeding maximum permissible concentration (over 0.10 mg/l) are recorded in the Bays of Volkhov and Svir. Shipping is the main source of oil pollution. Analysis have revealed the presence of oil products used in diesel and transformer oils in the lake water (Institute for Lake Research 1993).

Industrial waste from pulp and paper mills are also one of the main pollution sources of water and bottom sediments. They contain non-sulphate sulphur, lignosulphonates, phenols and salts of heavy metals (Institute for Lake Research 1993).

2.4.5
Heavy Metals

Mean concentrations of copper, zinc, lead and chromium in different parts of the lake water area differ little. Higher concentrations were found both in near-shore waters and in water masses of the other parts of the lake. Concentrations of arsenic vary little in different zones of the lake. Of all the near shore areas of the lake, the Volkhov and Svir Bays are noted for iron and aluminium concentrations which very often reach and exceed national maximum permissible values given to water system used as a raw water source. High concentrations of aluminium, manganese and iron exceeding maximum permissible values have been registered in the northern parts of the lake where waste waters from pulp and paper mills, wood works and various agricultural farms, as well as domestic wastes are discharged. Especially notable for this are Sortavala, Yakimvari, Kurkijoki, Impilahti and Hidenselka Bays (Institute for Lake Research 1993; see Table 4).

Table 4. Mean concentrations of metals (μg/l) in different zones of the Lake Ladoga from 1986-1989. Ranges of observed concentrations are presented in brackets. (Institute for Lake Research, Russia, 1993).

	Littoral zone total depth < 15 m	Slope zone total depth 15-52 m	Profundal zone total depth 52-89 m	Ultraprof. zone total depth > 89 m
Fe	225 (50-775)	106 (55-315)	73 (33-202)	68 (15-160)
Al	89 (22-325)	53 (13-185)	43 (12-125)	33 (10-78)
Mn	19 (2-100)	7 (2-95)	5 (1-32)	3 (1-5)
Cu	13 (1-103)	10 (1-105)	8 (1-100)	9 (1-70)
Pb	1.5 (0.3-9.3)	1.6 (0.2-26)	1.6 (0.1-8.9)	1.3 (0.2-4.2)
Zn*	60 (3-220)	55 (3-250)	52 (6-440)	60 (8-210)
Cr*	1.6 (0.4-3.3)	1.9 (0.4-5.9)	1.7 (0.4-3.3)	1.6 (0.5-4.4)
Cd*	0.2 (0.0-1.4)	0.1 (0.0-0.7)	0.1 (0.0-0.4)	0.1 (0.0-0.2)
As*	0.5 (0.2-0.8)	0.5 (0.2-1.0)	0.5 (0.2-1.0)	0.4 (0.2-0.8)

*) Data from year 1989.

Compared to the lake water the concentrations of iron and aluminium have been much higher in the rivers discharging into Lake Ladoga, but concentrations of copper and lead haven't been particularly high (data from years 1982-1983, see Table 5).

Table 5. Mean concentrations of metals (μg/l) in four rivers discharging into Lake Ladoga (years 1982-1983). Ranges of observed concentrations are presented in brackets. (Institute for Lake Research, Russia)

	Vuoksi	Svir	Volkhov	Syas
Fe	300 (90-550)	820 (260-2,630)	1,420 (620-2,460)	1,550(800-3,200)
Al	130 (80-290)	240 (50-630)	400 (220-900)	400 (200-600)
Mn	19 (10-30)	59 (10-130)	120 (38-200)	110 (32-210)
Cu	5.1 (1.5-13)	4.7 (1.0-10)	6.8 (3.0-12)	8.9 (3.5-22)
Pb	2.7 (1.0-9.8)	3.2 (0.8-11)	4.7 (1.7-8.0)	3.9 (1.6-8.0)
Co	1.9 (1.0-4.4)	3.0 (1.0-5.0)	6.9 (2.0-17)	8.7 (3.5-19)

According to more recent data in River Vuoksi a tendency towards an increase in iron, aluminium, copper and cobalt concentrations have been observed for several years. Thus, at present the mean annual concentration of iron in the river has its peak value compared with other tributaries and makes up 1,685 mg/l, that is 3 - 6 times higher than in the past. High concentrations of iron (maximum 4,000 μg/l), aluminium (maximum 1,200 μg/l), manganese (maximum 380 μg/l) in the River Vuoksi are either indicators of increased pollution of the river's water or the result of changes in the watershed's structure (Institute for Lake Research 1993).

In August 1993 observed metal concentrations were low (Niiniranta et al 1993).

2.4.6
Organic Halogenated Compounds

Traces of organochlorine pesticides are found all over the lake area (Viljanen & Drabkova 1992). The majority of persistent organochlorine pesticides are introduced into the lake from non-point sources (agricultural production). The highest pollution values in 1987 - 1989 were recorded in Sortavala (0.014 mg/l), Lahdenpohja (0.012 mg/l), at the source of the Neva 0.010 mg/l, western shore of the lake 0.005 mg/l (Institute for Lake Research 1993).

The results of the study carried out in 1991 in the northern part of the lake, at Sortavala archipelago and the area north of Valaam Island showed that organic halogen concentrations in the water were low and lower than in the clean area of Lake Saimaa, Finland. In Northern Ladoga the measured concentrations of Adsorbable Organic Halogens (AOX) varied between 18.8-26,3 μg/l (Pellinen & Soimasuo 1992).

2.4.7
Lignosulphonates

The pulp and paper industry is the most important loading source causing elevated lignosulphonate concentrations in Lake Ladoga (Viljanen & Drabkova 1992).

During the winters from 1987 - 1990, the concentration of lignosulphonates in the discharge area of Syas pulp and paper mill amounted to 7.7 mg/l, at Pitkaranta 10.5 mg/l. The background concentration is about 1 mg/l (Institute for Lake Research 1993).

2.4.8
Phenols

The pulp and paper industry is the most important loading source causing elevated phenol concentrations in Lake Ladoga (Viljanen & Drabkova 1992).

In 1988, mean concentration of highly toxic volatile phenols in the central part of the lake were in some places as high as 0.007 - 0.008 mg/l. High concentrations of phenols were found in the Volkhov Bay (0.004 - 0.008 mg/l), the Svir Bay (0.012 - 0.014 mg/l) and Petrokrepost Bay (0.004 mg/l). Phenol concentrations in the near shore zone close to the mouth of the Vuoksi were 0.006 - 0.01 mg/l (Institute for Lake Research 1993).

2.4.9
Methane

Discharge of organic substances by the pulp and paper industry affects the oxygen balance of the lake and cause increased methane concentrations (Viljanen & Drabkova 1992). High concentrations of methane have been observed in some periods in the shallows sections near Pitkaranta, Sortavala, Laskela (up to 30 mg/l), in the Janisjoki and Vuoksi Rivers (up to 117 mg/l) and smaller values - in the mouths of the Volkhov and Syas Rivers (4 mg/l). High concentrations of methane have been found also in the mouth of the Neva (24 mg/l). In the main part of the lake methane concentrations are low, not exceeding 1 mg/l (Institute for Lake Research 1993).

2.5
Hydrobiological Characteristics

The most drastic change in the lake's ecosystem occurred from 1976 - 1983, when processes of anthropogenic eutrophication accelerated due to the growth of biogenous load. Certain stabilization of the situation in the lake was observed in 1983 - 1984, but at a different quantitative level. Biological communities have changed considerably both structurally and physiologically in the areas of heavy pollution (Institute for Lake Research 1993).

2.5.1
Algae

Up to the beginning of the 1960's Lake Ladoga was an oligotrophic lake where diatoms were dominant in the phytoplankton. The number of phytoplankton species has increased considerably since 1960's. At present there is 22 main algae species and each of them has 1 million cells per liter, whereas in 1962 only three species were so numerous. According to the literature in summer the development of the *Microcystis* is strongest in the south, whereas in the central and northern parts the *Aphanizomenon* complex is typical of this period of mass development of blue-green algae (Lepistö 1990).

The seasonal complex of algae had changed in the period of intensive anthropogenic eutrophication of the lake: the species typical of eutrophic lake added to those of oligotrophic lake. It could be clearly seen in the example of summer plankton in which blue-greens began to dominate sharply and there were almost no diatoms. A new stage began after 1984; diatoms from the oligotrophic period started to supplant the eutrophic species more and more noticeably (Institute for Lake Research 1993).

By 1989, the composition of summer dominant phytoplankton was practically identical to that observed in the oligotrophic period (1956 -1962) (Petrova, Antonoc, Protopopova 1992; ref. Institute for Lake Research 1993). The period of intensive anthropogenic eutrophication of the lake was characterized by maximum concentration of chlorophyll-a (mean summer concentrations reached 2.6 -2.8 mg/l in that period, compared with 1.6 - 2.0 in 1984 - 1989). That period was also noted for maximum variation range of those values - maximum concentration of chlorophyll-a exceeded mean ones by 15 - 17 times, whereas after 1984 by 7 - 9 times (Institute for Lake Research 1993).

In summer 1990 the highest concentrations of chlorophyll-a were observed in warm areas like the Bay of Svir (9.1 μg/l) and in the archipelago of Sortavala (26 μg/l). In the Bay of Volkhov concentration (7.5 μg/l) was not particularly high, and in the central parts of the lake concentration was actually rather low (3.2-5.4 μg/l). The chlorophyll concentrations were measured using continuous flow fluorescence measurement equipment which was installed on a research vessel for the depth of one meter (Kovalenko 1990).

In July 1990 phytoplankton biomasses at a depth of 0-2 m were measured at 6 sampling stations. Biomasses ranged between 1.12-2.90 mg/l (freshweight). The highest biomass measured (2.90 mg/l) indicated eutrophy, other biomass values (1.12-2.05 mg/l) indicated mesotrophy. Cryptophytes were the dominating group (mostly 50 % of the biomass) in the studied material, mostly *Cryptomonas* spp. and *Rhodomonas lacustris*. Blue-green alga *Anabaena circinalis* made up 30 % and 20 % of the biomass at two sampling stations, at the other four stations the biomass of blue-green algae was relatively low. The number of taxons was generally equal at all sampling stations (Lepistö 1990).

According to secchi disk measurements water transparency varies between 1.8-3.3 m (Viljanen & Drabkova 1992).

2.5.2
Bacteria

Quantitative characteristics of micro-organism communities vary greatly in different parts of the lake; from the lowest in the mesotrophic lakes (in profundal and ultra-profundal zones) to the values typical of eutrophic water bodies (in southern bays and areas affected by pulp and paper mills) (Kapustina 1992, ref. Institute for Lake Research 1993). As for the bacterioplankton number, the situation has stabilized in recent years (Institute for Lake Research 1993).

Thus the number of bacteria in epilimnion increased on average from 0.4 to $0.9\text{-}1.0 \cdot 10^6$ counts/ml for the period of 1977 - 1982 and stabilized at the level of $0.7 - 0.86 \cdot 10^6$ counts/ml in 1982. It continued to grow in hypolimnion until 1985. In spite of this, a tendency towards an increase in CO_2 heterotrophic assimilation intensity in deep-water areas was observed in recent years. Apart from the high total number of bacteria, considerable quantities of conditionally pathogenic bacteria have been recorded in the near shore polluted areas near Priozersk, Pitkaranta and Petrokrepost. Their number is especially high in bottom sediments. Thus the concentration of lactose positive bacterium coli and faecal streptococci reaches up to dozens of thousands per 1 kg of soil (data by Seluzitsky and Vorobyeva; ref. Institute for Lake Research 1993).

2.5.3
Zooplankton

The biomass of zooplankton vary in different parts of the lake from average values which is typical of eutrophic water bodies. Vertical differences are accompanied by considerable horizontal differences; centres of eutrophication are being observed which is also typical for other big lakes of the world (Institute for Lake Research 1993).

In the study carried out in July-August 1990 the lowest numbers of zooplankton species were observed in the bays of Svir and Volkhov with 15-16 species. In other areas species number varied between 23-27 (Kulikova 1990).

In July-August 1990 the most productive layer, as usually in summer, was the surface layer (0-5 m). Rotifers were observed most often and also in greatest numbers in the surface layer. Species *Polyarthra major* and *Keratella cochlearis* were common and a little less common were genera *Kellicottia* and *Euchlanis*. In the bays of Svir and Volkhov the zooplankton consisted almost entirely of rotifers (99 % of the total biomass) (Kulikova 1990).

In July-August 1990 Cladocera species composition varied to some extent depending on the location of sampling station. In the surface layer typical species were *Daphnia cristata*, *Bosmina obt. lacustris*, *B. coregoni lilljeborgi* and *Chydorus sphaericus*. Also *Bosmina crassicornis* was observed. At some stations Cladocera formed the main proportion of the zooplankton biomass in the surface layer. In addition to Cladocera the Copepods reproduce actively in the surface water layer. Typical species were *Eurytemora lacustris*, *Mesocyclops leuckarti* and *Thermocyclops oithonoides* (Kulikova 1990).

The total number of zooplankton in the surface water layer appeared in July-August 1990 with 81,400-1,030,000 counts/m^3 and the biomass was correspondingly 200-1,680 mg/m^3. Quantitatively the most important groups of zooplankton were in most areas Cladodera species and Copepods *Mesocyclops leuckarti* and *Thermocyclops oithonoides* (Kulikova 1990).

Mass development of rotifer and depression of crustaceans occurs in polluted areas. These processes are more intensive in the Petrokrepost Bay and in the Volkhov Bay. In those areas the rate of zooplankton biomass turnover has increased which has resulted in intensification of the self-purification process, but the quality of the food basis of plankton-eating fish has sharply deteriorated (Institute for Lake Research 1993). In July-August 1990 it was observed that zooplankton biomasses reached their maximum near the discharge points of pulp and paper mills. In these areas, where there is a lot of organic matter due to the effects of waste water, there is a lot of food for filter plankters and therefore dense population of plankton as well (Kulikova 1990).

Concurrently with the eutrophication of Lake Ladoga, there are many negative cosnequences of the various types of pollution such as an increase in saprobity and toxicity of water. As a result of this, the most sensitive species and forms disappear from the planktic and benthic communities (Institute for Lake Research 1993).

At deep water sampling stations zooplankton biomasses were quite low in July-August 1990. Cladocera *Daphnia cristata* and small cyclopoda (*Mesocyclops*) played an important role in the biomass, although the proportion of rotifers was also significant (Kulikova 1990).

The average biomass of zooplankton in Lake Ladoga indicates mesotrophy. The biomass varies greatly between different areas; from the low values typical to mesotrophic water bodies in the deep areas to values typical to eutrophic water bodies in the southern bays. The amount of summer zooplankton biomass in the deep parts of Lake Ladoga is today two to three times higher than 30 years ago. It has increased from 8.2 g/m^2 (year 1948) to 28 g/m^2 (year 1978) (Kulikova 1990). In August 1983 in the central part of Lake Ladoga the average zooplankton biomass of the whole water column was in the range of 6.1-19.4 g/m^2 (Rahkola et al 1992).

In the bays the increase in biomass has been considerable during the past 20 years. As the total number of species has decreased, there have been structural changes. The number of large form like calanoids has decreased and the number of small forms like Cyclopoda, Cladocera, and rotifers have increased. The increase in the number of the eggs of crustaceans, which was observed in year 1990 study, is also a sign of the eutrophication (Kulikova 1990).

2.5.4
Benthic Fauna

There has been little or no change at all in the level of bottom invertebrate development in ultra-profundal and profundal zones for the last 10 years. In the near shore and slope zones an increase in the number and biomass of benthos was recorded which led to differences in the trophic level determined by phytoplankton indices and by zoobenthos (Slepukhina 1986, ref. Institute for Lake Research 1993).

As a result of pollution and lack of oxygen, "dead zones" lacking bottom fauna have formed near Pitkaranta, Priozersk and Laskela. Bottom fauna is being gradually restored after the closure of the Priozersk pulp and paper mill in 1986 (Institute for Lake Research 1993).

In a study carried out in 1990 and 1991 in the profundal zone of the northern part of Ladoga it was observed that the total numbers of meiofauna were in polluted areas mostly between 100,000 and 250,000 ind./m^2 and in cleaner deeper areas about 50,000 ind./m^2 or less. For a very large lake like Ladoga it seems to be characteristic that the effect of pollution is seen only in a small area. Species diversity is high even in polluted areas, the species preferring oligotrophy can occur even at comparatively polluted areas and the bottom can be hard and poor in meiofauna even at great depths (Särkkä & Kurashov 1992).

Serious morphological deflections have been observed in the organisms of Lake Ladoga (chironomid larvae, in particular) under the effect of a toxicant. Symptoms of profound pathology also in the zooplankton community were registered in the area near Pitkaranta (Andronnikova 1991, ref. Institute for Lake Research 1993).

In a study performed in October 1991 in the Sortavala archipelago considerable recent improvements in ecological conditions were revealed near Läskelä settlement due to the reductions of pulp and paper mill effluent discharges into the Jänisjoki River (Davydova et al 1992).

2.5.5
Fish

The increasing economic activity in Lake Ladoga's basin adversely influences the fish stock of the lake. Fish are sensitive bioindicators of an ecosystem's health and respond to anthropogenic effects by changing species composition, biomass proportions of some species, values of commercial fish stocks and catches (Kudersky 1984, ref. Institute for Lake Research 1993). All these forms of fish response are observed in Ladoga. The stocks of such lake-river fish as the Volkhov whitefish, salmon and lake trout have sharply reduced in the last decade. In the 1930's the catches of salmon amounted to 160 tons and lake trout to 40 tons annually. At present, lake trout has no commercial importance and salmon catches make up 1-5 t/a (Institute for Lake Research 1993).

In the 1970's, commercial catches of lake whitefish amounted to 600 t/a, and in 1986 - 1990 they fell to 300 and less. Toxicosis was observed in many fish species in some areas, e.g. up to 70 - 80 % of whitefish, pike perch, bream, roach and ruff species suffer from toxicosis in the Volkhov Bay. In the same area the meat from 20 - 60 % of the fish under study smelt of oil. In the Svir Bay, toxicosis was found in 50 - 60 % of the studied fish species; 30 - 60 % in the mouth of the Vidlitsa River (Arshanitsa 1988, ref. Institute for Lake Research 1993). Chinareva (1988, ref. Institute for Lake Research 1993) observed oedema and dissociation of fibres, accumulation of hemosiderin in the spleen, grain degeneration of liver, hemorrhage in the kidneys and stones in the kidneys in fish species in the Volkhov and Shlisselburg Bays.

2.6
Bottom Sediments

According to Semenovits (1966 ref. Sandman & Kalmikov 1990) the quality of the bottom of Lake Ladoga varies a lot. A boulder bottom is typical for the northern parts of the lake where the shores are rocky. There are a lot of boulders in narrow zones at the water's edge where they alternate or occur together with sand areas. In places where the moraine has been washed away the bottom consists merely of boulders. They form of ridges and shallows even further away from the shores (Sandman & Kalmikov 1990).

Pebble and gravel occur together with small boulders and sand as separate deposits along the whole shallow southern littoral area and as separate areas along the western and eastern shores. Sand with different degrees of coarseness is present everywhere along the shallow southern littoral area and as a zone along the western and eastern shores where sediments from the

Quaternary period have been deposited on it. In the northern part of the lake where the shores are rocky there is little sand. The coarseness of the sand by the shallow, southern shore varies in the surface layer from the partly muddy sand-aleurone sediment in its different degrees of coarseness often mixed with gravel (ref. Sandman & Kalmikov 1990).

Coarse and fine aleurone gyttja also occurs in a limited area in the transition zone between shallow and deep waters. In the fjord area the dominant soils are also different muds (clay and aleurone gyttja). The bottoms of the deep central and northern parts of the lake consist of clay gyttja. The clays on the bottom of Lake Ladoga are mostly watery, soft and have a porous structure. The latter mentioned character is typical especially of the sediment of the profundals (ref. Sandman & Kalmikov 1990).

The specificity of sediment distribution is such that finely dispersed sedimentary material (mineral and organic), discharged by the Volkhov, Svir and other tributaries located on the southern and eastern shores, as well as organic matter from more productive southern and eastern parts of the lake, may be transported to the north and may accumulate in the peripheral part of the deep water area and in the Pitkaranta shallows in the north-eastern part of the lake (Institute for Lake Research 1993).

2.6.1
Organic Matter and Nutrients

Organic matter content (evaluated as loss on ignition, % of dry weight) increases from sands (0.19 - 2.50 % to clay silts (1.54 - 12 %). The highest concentrations of organic matter (12 %) in the deep-water zone were found along the periphery (depths of 40 - 50 m) of the slope zone. Organic matter content is mainly within a 2 - 5 % range in the profundal and ultra-profundal zones. Maximum concentrations of organic matter (up to 43 %) have been recorded in the polluted areas of the shallow water where waste waters from pulp and paper mills were discharged (Institute for Lake Research 1993).

In July 1990 the quality of sediment was investigated at two sampling stations at a depth of 50 m and 65 m. At the first station (depth 50 m) the ignition loss at the sediment depth of 0 cm to 4 cm varied between 6.7-8.7 % of the dry weight (DW). Total phosphorus concentration ranged between 1.5-2.0 mg/g DW and total nitrogen ranged between 1.0-3.3 mg/g DW. At the second station (depth 65 m) the ignition loss at the sediment depth of 0 cm to 4 cm varied between 12.0-13.4 % of the dry weight (DW). Total phosphorus concentrations ranged between 1.6-2.3 mg/g DW and total nitrogen ranged between 3.1-4.4 mg/g DW (Sandman & Kalmikov 1990).

2.6.2
Heavy Metals and Organic Halogen Compounds

Spatial distribution of the following elements in the bottom sediments were studied from 1986 - 1991: iron, manganese, copper, nickel, cobalt, vanadium, chromium, lead, gallium, barium, strontium, titanium and zinc. It was found that concentrations of the majority of the elements under study, except for zinc and strontium, grew from sands to clay-organic-mineral silts. This regularity proves that the majority of elements (Fe, Ni, Co, Cu, V, Cr, Ti, Ga, Pb) are bound up with clay organic-minerals in processes of sediment formation. They migrate and accumulate in sediments together (Institute for Lake Research 1993).

It was found that mechanical dispersion of sedimentary material was a major factor in the accumulation of heavy metals in sediments of different parts of the lake. That is why the effect of hydrodynamic processes is of great importance in assessing general and local peculiarities of heavy metals distribution in sediments. It is the specificity of the hydrodynamic factor in the open part of the lake that determines maximum accumulation of clay organic mineral material and elements bound up together in peripheral part of the profound zone (Institute for Lake Research 1993).

High concentrations of organic matter (up to 43 %), polychlorinated biphenyls (PCBs), non-sulphate sulphur (0.74-1.3 mg/kg dry weight), benzopyrene (66-550 mg/kg dry weight) and association of heavy metals (Cu, Pb, Ti, Ga, Co) bound up with sulphide compounds are characteristic of the sediments in the locations receiving pulp and paper mill waste water discharges (Priozersk, Laskela, Pitkaranta). Maximum high concentrations of these elements are recorded in the bays. It has been found that the transport of polluted sedimentary material from the bays into the open lake depends on local bottom relief, the activity of water currents and the openness of bays (Institute for Lake Research 1993).

In closed bays the sedimentation of polluting components in deep water depressions creates an unfavourable sanitary - toxicological situation. Although toxic elements have a constant tendency to accumulate in the depths of the bay near Priozersk and in the Pitkaranta shallows, sedimentary material is transported to the open lake (Institute for Lake Research 1993).

The results of a study carried out in 1991 in the northern part of the lake at Sortavala archipelago and the area north of Valaam island showed that organic halogen concentrations in the sediment was low and lower than in the clean area of Lake Saimaa, Finland. In Ladoga the measured concentrations of organic halogens in sediment varied between 7.3-24.4 mg/kg on a dry weight basis (Pellinen & Soimasuo 1992).

2.7
Epidemiological State of the Lake

Epidemiological observation carried out by St. Petersburg Institute of Sanitary and Hygiene in some areas of Lake Ladoga's basin revealed higher disease and death rates among the population caused by a class of diseases, including malignant tumours, etiologically related to water. It is especially typical of the areas where sources of potable water are affected by pulp and paper mill waste water discharges (Institute for Lake Research 1993).

Based on 25 years of observations in the pulp and paper mill areas the share of digestion and urinary diseases affecting the total death rate has continually increased and is double that of the control area (Vyborg). The high death rate caused by oncological diseases is also typical for these areas. Stomach cancer is most common exceeding the corresponding rate in the control area by 1.5 times. The rate of stomach cancer in these areas increased by 7 times (by 2 times in the control area) for the period of 1960-1985. High death rates from kidney and bladder tumours have also been observed in the above-mentioned areas (Institute for Lake Research 1993).

2.8
Pollution

594 industrial and 680 agricultural enterprises are located in the territory of the lake basin. Machine-building, wood-working, pulp and paper and chemical industries are developed in the watershed. A very important role is played by dairy and meat livestock breeding. Of all the industries the most water-consuming are wood-working and pulp and paper, using 23 % of total industrial water consumption. Non-ferrous metallurgy consumes 5 %, chemical and petrochemical industries 3.4 % (Institute for Lake Research 1993).

According to the data of State Water Use Inspection, 1.4 km^3 of waste waters are discharged annually into Lake Ladoga's basin, corresponding to the 44 m^3/s continuous mean flow of waste water. This amount includes 17 % of untreated and only partially-treated waste water. Annually, approximately 54.6 km^3 of clean water corresponding continuous flow of 1,700 m^3/s is required to dilute waste waters to the level of national maximum permissible concentrations for raw water sources. This calculatory flow of dilution water makes up 6 % of the total lake volume and 73 % of the annual inflow (Institute for Lake Research 1993).

The measured or estimated loading of pollutants entering Lake Ladoga is shown in Table 6.

Table 6. Pollution of Lake Ladoga; situation at the end of the 1980's and beginning of the 1990's. Figures are presented with an accuracy of two significant numbers.

	t/a	Source of information
Total phosphorus	7,300	see appendix 3
Total nitrogen	82,000	see text below
Biological oxygen demand	8,400	see text below
Oil products	1,800	Institute for Lake Research 1993
Zinc	40	Institute for Lake Research 1993
Chromium	55	Institute for Lake Research 1993
Cadmium	12	Institute for Lake Research 1993
Lead	3.6	Institute for Lake Research 1993
Phenols	180	Institute for Lake Research 1993
Chlorinated organic compounds	2,500	Institute for Lake Research 1993

The BOD estimate presented in Table 6 includes only point source loading: major municipalities, industry enterprises and livestock farms. In calculations, values based on direct measurements of BOD load were used when available. If they were not available the loadings from municipalities and livestock farms were estimated by using specific loading values and the number of inhabitants in municipalities and number of heads in farms. For inhabitants the value of 18 kg BOD/person·was used and for cattle (cows) 11 kg BOD/head·was used.

Point source nitrogen loading estimates were calculated in the same way as BOD loading. The specific loading values were 4 kg N/person·a and for cattle (cows) 2.5 kg N/head. As a result the point source nitrogen loading was estimated to be 5,000 t/a. The non-point nitrogen load was estimated to be 270 kg/km^2·a for the whole drainage area based on studies carried out in Finnish drainage basins including both forest and cultivated soil. Using this method the non-point nitrogen load was estimated to be 77,000 t/a.

On the basis of field research results it has been possible to detect some areas where economic activity has influenced the water quality more clearly than in others. For example by the mouth of Jänisjoki River, which receives the water from the pulp and paper mill of Läskelä, the bottom of the lake is covered with pulp, the oxygen concentration is only 4 mg/l, and the phenol concentration 4-6 mg/l. An oxygen-free zone with a breadth of 200 m has been formed by the southeastern shore of the Bay of Volkhov due to the pulp and paper mill of Sääski, and the concentration of organic matter has risen in a zone 5 km broad. The polluted water of Volkhov River is spread along the eastern shore up to the island of Valaam (Filatov et al 1990).

The most severe environmental effects of the pulp and paper industry have been recorded near River Syas, Priozersk, Läskelä, and Pitkäranta (Viljanen

& Drabkova 1992). Due to discharges from the pulp and paper mill of Sortavala the oxygen concentrations in the archipelago of Sortavala have decreased to 6.5 mg/l in the surface layer in summer, and to 1-3 mg/l at the depth of 13-25 m (Filatov et al 1990).

A considerable part of the surface of nearshore areas are occasionally covered by oil film (Filatov et al 1990).

2.9
Ladoga as a Raw Water Source

The summary of water analysis results from samples taken from 22 locations in Lake Ladoga in August 1993 by Finns (Niinioja et al, 1993) is presented in Appendix 5. The comparison between those results and raw water classification in Russia, Finland and th EU is presented in Table 7. Results from location 2 are printed separately because it is nearest to the raw water intake location. This water might be transferred to St. Petersburg according to a plan introduced later in this report.

Table 7. The comparison between Lake Ladoga water quality and the raw water classification in Russia, Finland and the EU

Parameter	Unit	Observed Values in Lake Ladoga		Russian GOST norm maximum	Finnish classification	EU directive
		average of 22 locations	location 2			
A-chlorophyll	mg/l	(10)(1	(5)(1		III / II	
Coloration	mg/l Pt scale	35	30	35	II	A2
COD_{Mn}	mg/l	8.4	7.2	7	II	OK
Oxygen	%	95	99		I	A1
pH		7.6	7.8	6.5-8.5	II	A1
Phosphorus$_{tot}$	mg/l	24	13		II	
Secchi disk transparency	m	2.3	2.5		III / II	

(1	estimated according to phosphorus concentration
A1	simple physical treatment and disinfection needed
A2	normal physical and chemical treatment and disinfection needed
I	excellent
II	good
III	satisfactory

According to Finnish classification the water of Lake Ladoga is "good" for the production of potable water. Bacteria, A-chlorophyll and mineral oil concentrations were not observed, but in cleaner parts of the lake they probably would not change the classification. According to EU directives water could be used for drinking after normal physical and chemical treatment and disinfection.

3
PRESENT STATE OF NEVA RIVER

3.1
Hydrological Regime

The total catchment area of the River Neva is 285,000 km^{2}· including the area covered with lakes. The mean discharge of the river is about 2,600 m^{3}/s. Neva River is relatively short, 74 km, and it's direct catchment area (small tributaries discharging directly to Neva) is about 5,000 km^{2} (Russian Research Institute for Agricultural Microbiology 1993).

3.2
Chemical Composition of the Water

The water quality in the upper course of Neva has a strong correlation with eutrophication and pollution processes in Lake Ladoga. Nevertheless, the following three arguments should be taken into account:

1) Poisons and other compounds which are harmful near discharge areas are diluted with huge water volumes before they reach the Neva.

2) About 70 per cent of phosphorus entering Lake Ladoga remains in the lake.

3) Most of the algae growing in the lake also stays and dies there.

The mean concentration of total phosphorus in Neva at the lake outlet is constantly a little higher than the mean concentration in Lake Ladoga. This is caused by local factors near the lake outlet and occasionally transit currents from the mouths of rivers Vuoksi, Volkhov and Syas into the lake outlet (Rumjantsev & Rodionov 1991). During transit the water from the river discharging into Lake Ladoga doesn't mix effectively with lake water but is instead transported relatively separately to the lake outlet. The annual average total phosphorus concentration in Lake Ladoga is about 25 μg/l and is 2 - 5 times higher in rivers Vuoksi, Volkhov and Syas. Therefore, annual average concentrations in Neva have been 31 μg/l in years 1981-87 and 27 μg/l in 1989, 26 μg/l in 1990 and 27 μg/l in 1991 (Institute for Lake Research 1993). During strong transit circumstances, storms and spring melting total phosphorus concentration can raise to 70 - 80 μg/l (Rumjantsev & Rodionov 1991).

At the upper reaches of Neva the average total nitrogen concentration is 680 μg/l and the concentration varies between 400-1,150 μg/l. Concentration of suspended solids at the lake outlet is about five times higher than the average concentration in Lake Ladoga. This is caused by suspension of bottom sediments at the shallow areas near the lake outlet and flood waters during spring and autumn seasons. There is information in Table 8 concerning certain compounds which describe the pollution situation in the upper course of Neva River. High BOD_5, phenol, oil, copper and lead concentrations have a relation to the antrophogenic load, but manganese comes mainly from natural sources (Rumjantsev & Rodionov 1991).

Table 8. Water quality in upper course of River Neva 1982 - 1987 (Rumjantsev & Rodionov 1991).

Compound	Highest permissible according to GOST-norm	Annual Average	Maximum
BOD_5 mg O_2/l	2	0.7-2.4	3.6
Phenols µg/l	1	1-4	9
Oil µg/l	50	30-80	130
Polyaromatic hydrocarbons µg/l	100	15-25	62
Copper µg/l	1	0.6-8	13
Lead µg/l	30	0.2-18	104
Manganese µg/l	10	3-32	120
Cadmium µg/l	1	0.1-0.4	
Quicksilver µg/l	0.5	0-0.1	0.3

The Neva is considerably loaded with direct waste water discharges or those through its relatively small tributaries. Only a little point source loading enters the river above the mouth of River Izora and most waste water loading is discharged within the City of St. Petersburg. Along the Leningrad region part of the river phosphorus concentration rises about 3 µg/l and about 40 µg/l along the St. Petersburg part (Russian-Finnish Joint Commission of Environmental Protection, 1993). Phosphorus concentrations are reported to be 70 - 80 µg/l at the mouth of the Neva (Rumjantsev & Rodionov 1991). Increases in the phosphorus concentration can be assumed to reflect other components of waste water as well.

3.3
Neva as a Raw Water Source

The summary of reported results from the water analysis of present water plants during 1985 and from 1990 - 1993 are presented in Appendix 6. The comparison between the results representing the raw water of SWTP and raw water classification in Russia, Finland and EU is presented in Table 9. Raw water quality is basicly the same in other water treatment plants as well, except for the contents of bacteria which have been over 10 times higher in MWTP and PWTP.

Table 9. The comparison between reported Neva water quality and the raw water classification in Russia, Finland and EU

Parameter	Observed Values in Neva (SWTP) typical	maximum	Russian GOST Norm maximum	Finnish Classification	EU Directive
Ammonia mg/l	0.2	0.5	2	III	A2
A-chlorophyll mg/l	(12)(1			III	
Coloration mg/l Pt scale	28	35	35	II	A2
COD_{Mn} mg/l	7.5	10	7	II	OK
Faecal colif. (44 °C) /100 ml	1400	7000		V	A3
Total colif. (35 °C) /100 ml	(1500)(2			V	A3
Nitrate mg/l	1.9	3.1	45	OK	A1
Nitrite mg/l	0.024	0.033	33	OK	
Mineral oils µg/l	50	300		IV	
Oxygen mg/l	11		> 4	I	A1
pH	7.3	8.0	6.5-8.5	II	A1
$Phosphorus_{tot}$ mg/l	27			III	

(1 estimated according to phosphorus concentration
(2 individual sample taken by Finnish authorities
A1 simple physical treatment and disinfection needed
A2 normal physical and chemical treatment and disinfection needed
A3 intensive physical and chemical treatment and extended treatment and disinfection needed
I excellent, II good, III satisfactory, IV poor, V unsuitable

According to the Finnish classification the water of River Neva is unsuitable for the production of potable water, because of the **high contents of total and faecal bacteria**. High bacterial concentrations indicate remarkable excrement loading originating mainly from municipal sewage and cattle breeding. According to EU directives water could be used for the production of drinking water only after extensive purification (ozonation and active carbon filtration).

If bacteria is not taken into consideration, the water would be classified by Finnish standards as "satisfactory" because of ammonia and phosphorus concentrations and temperature. Phosphorus concentrations and temperature are favorable for the growth of algae. The concentration of chlorophyll-a during the growing season would probably be in level "satisfactory" as well. Information concerning chlorophyll-a was not available, but it may be estimated according to the phosphorus concentration and other measured values at the Lake Ladoga outlet. The probable level is about 10 µg/l during the growing season.

According to the concentration of oils the water would be classified aas "poor" if the figures represent mineral oils. In other respects the Neva would be classified by Finnish standards as a "good" or "excellent" raw water source.

4
FUTURE WATER QUALITY ACCORDING TO PROJECTED DEVELOPMENT SCENARIOS FOR LAKE LADOGA AND NEVA RIVER

4.1
General

Objectives set by mutual agreement concerning water protection measures between the Finnish Republic and the Russian Federation are the basic outline for the development of Neva River catchment area. Due to the fact that it is impossible to put the action plan into practice the planned date (1995) 0- and intermediate alternatives are taken into account.

The importance of Lake Ladoga to the water supply of St. Petersburg is emphasized by the fact that the Neva, practically the only raw water source for St. Petersburg, is the only waterway from Lake Ladoga to the Gulf of Finland. Therefore, the Ladoga catchment area also belongs to the catchment area of the Neva and hence the Gulf of Finland. The water quality of the Neva is dependent on the water quality of Lake Ladoga. Anyway direct waste water discharges into the Neva or its tributaries are of great importance.

Despite the enormous flow of the Neva compared to its tributaries and a length of only 74 km, the quality of water is significatly worse at the end of the river compared to the begining. The water quality at the outlet of Lake Ladoga is much worse than average in the lake. The quality remains at the same level from the lake outlet at least to the mouth of Izora River.

Phosphorus loading is believed to be the most significant pollutant in Ladoga and therefore it is chosen as a key parameter in observing future scenarios for the development of the ecological status of Ladoga. The first task was to compile the information available concerning phosphorus loading to Lake Ladoga. This procedure is described in the following paragraphs before presenting the development scenarios based on these results.

4.2
Present Phosphorus Loading

For more than 25 years the lake has been under a heavy anthropogenic load. The dominating role of phosphorus in the formation of the anthropogenic eutrophication process is now evident. The main sources of phosphorus discharge are the rivers Volkhov, Svir and Vuoksi (Institute for Lake Research 1993).

Volkhov River, with an aluminium producing plant located near the mouth of the river, has a very high concentration of phosphorus compounds in its waters and is the biggest single phosphorus loader of the lake. The highest concentrations of phosphorus in the Volkhov water was recorded in the 1960's and 1970's were caused by the aluminium producing plant using apatite-nepheline as raw material. Since 1984 phosphorus discharges into the Volkhov have decreased due to the water protection measures taken at the plant (Institute for Lake Research 1993). Volkhov's aluminium plant is still maintains a phosphorus load of 290 t/a (1990), Ladoga's largest point-source phosphorus loader.

The closure of the Priozersk pulp and paper mill in 1987-1988 decreased phosphorus discharges into Lake Ladoga. However, concentrations of total phosphorus tend to increase in the waters of the Svir and Vuoksi rivers (Institute for Lake Research 1993). The Svetogorsk plant at Vuoksi has an estimated phosphorus load of 210 t/a, the second biggest point-source phosphorus loader for Lake Ladoga. According to calculations based on measurements conducted in the river above and below the plant, the loading may occasionally be even greater than 210 t/a.

The present loading from Finnish sewage point sources into southern Lake Saimaa is 31 t/a which is minimal compared to the total load from point sources within the catchment area of Lake Ladoga. About 25 per cent of total phosphorus load of the Vuoksi comes from Finland. This represents only 3 per cent of Lake Ladoga's total phosphorus load.

Differences and inaccuracies between different sources of data available during this study reinforced the necessity to conduct a comparison procedure displaying these differences. For this purpose the sources of initial data used in this study are listed in Appendix 2.

The reported total phosphorus discharges into Lake Ladoga vary roughly between 6,000-8,000 t/a. Petroca et al (1991, ref. Russian Institute for Lake Research 1993) have estimated that a phosphorus load which would enable Ladoga to achieve its original ecological status (oligotrophy) would be about 4,000 t/a.

External phosphorus loading figures provided by the Russian Institute for Lake Research indicate that there are considerable yearly variations. The loading estimate for the 1989 was 6,129 tons, for 1990 5,790 tons and for 1991 8,220 tons. Variations in hydrological conditions are probably the main reasons for variations in loading. River discharges of phosphorus into Lake Ladoga are presented in Figure 7.

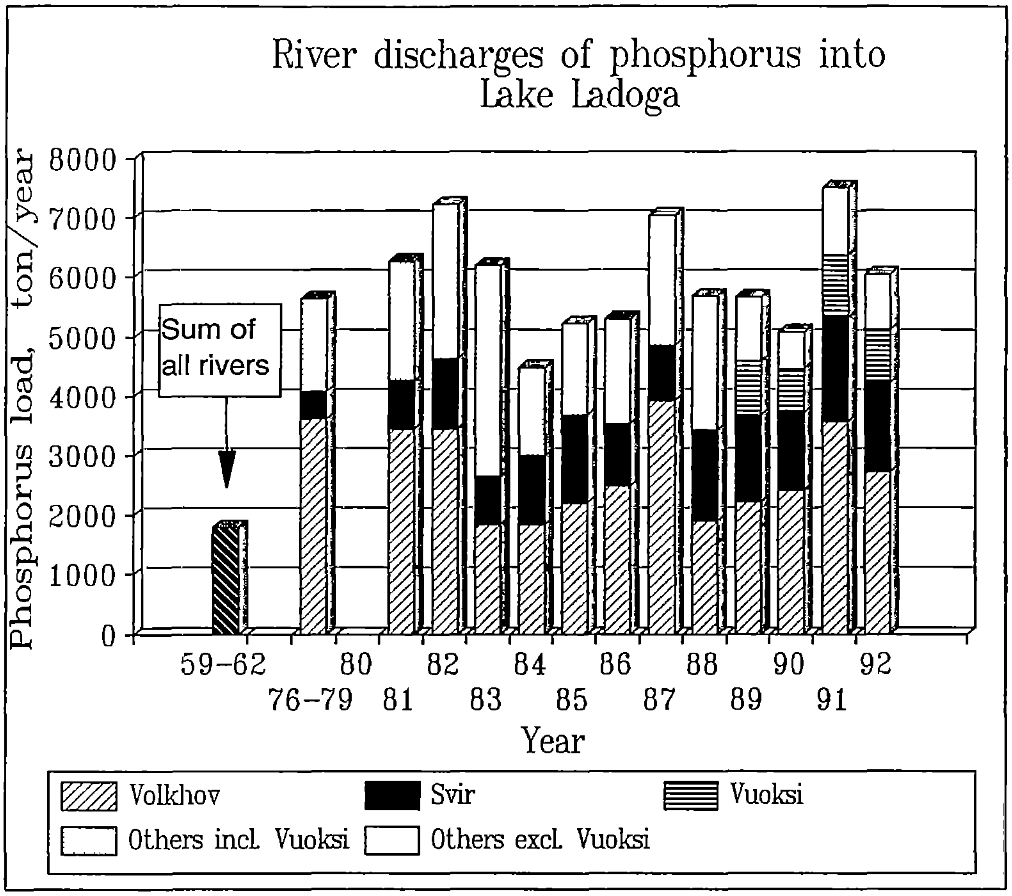

Figure 7. River phosphorus discharges into Lake Ladoga. (Source of information: Russian Institute for Lake Research.)

According to the information concerning 1989-91 (provided by the Russian Institute for Lake Research) the amount of total external phosphorus from the three main rivers entering Lake Ladoga was as follows: the Volkhov 36 - 43 %, the Svir 21-24 % and the Vuoksi 11-15 %. During the same period the annual mean total phosphorus concentrations in the Volkhov ranged between 82-135 μg/l, in the Svir between 59-90 μg/l and in the Vuoksi 42 - 64 μg/l.

Further division of the phosphorus load, according to different sources, is more difficult. In order to determine the right level of point-source pollution and to ease the further strategic estimations, loading figures from the following point-source polluters of the catchment area were studied:

- municipalities with inhabitants of 10,000 or more
- significant industrial enterprises
- large livestock breeding complexes

The summary of the study is presented in Table 10. Detailed results are presented in Appendixes 3-4.

Table 10. Summary of average phosphorus loads from drainage waters into Lake Ladoga.

	Point source load, t/a	Non-point source load t/a	Natural load, t/a	Total load, t/a
River Volkhov	610	1,830	120	2,560
River Svir	40	1,380	90	1,510
River Vuoksi total	490	380	130	1,000
(share of Finland)	(30)	(250)		(280)
Rivers Syas, Pasha and Oyat	120	640	180	940
Drainage from small rivers and direct drainage	90	850	420	1,360
Total load from drainage waters	1,350	5,080	940	7,370

4.3
Development Scenarios for Lake Ladoga

The development scenarios for the projected phosphorus loading of Lake Ladoga are based on the results of the phosphorus discharge study and its division between different sources. Three different scenarios were chosen for further analysis. They are as follows:

Scenario 1. The 0 - solution:

- Pollution level will stay at the present level.
- Phosphorus load: 7,400 t/a.

Scenario 2. The intermediate solution:

- This alternative is based on the assumption that half of the water protection measures described in scenario 3 can be implemented.
- Phosphorus load: 5,700 t/a.

Scenario 3. A solution based on mutual agreement between the Finnish Republic and the Russian Federation with the following objectives for phosphorus loading to be achieved during 1995:

- for municipalities with 10,000 inhabitants or more:
  90 % reduction of loading including bypasses and overflows

- for industry in general:
  50 % reduction of loading from 1987 pollution level
- for pulp & paper industry:
  60 gram of phosphorus/ ton of bleached pulp/ year
- for agriculture and forestry:
  50 % reduction from 1987 pollution level

- Phosphorus load: 4,000 t/a.

At the major phosphorus point-sources the best available technology (BAT) will be utilized, though not mentioned in the agreement.

The mutual agreement between the Finnish Republic and the Russian Federation includes other objectives apart from those for phosphorus discharges. These objectives include substances causing oxygen demand (BOD) and chlorinated organic substances (AOX).

The more detailed phosphorus loading figures for the above mentioned scenarios are presented in Appendix 4.

4.4
Cost Estimates

Rough estimates for investment costs needed for water protection measures to achieve the agreed targets within the Russian parts of the water drainage area of Lake Ladoga (Scenario 3) are as follows (information sources mentioned in appendix 2):

-	Municipalities over 10 000 inhabitants (20 units together appr. 0.7 million inh.)	220 mUSD
-	Industry (information available concerned only the biggest 20 enterprises)	150 mUSD
-	Agriculture (basicly livestock farming)	80 mUSD
		450 mUSD

The cost of waste water treatment plants have been calculated according to the traditional activated sludge process. Most of the municipalities discharge their waste waters without any treatment. In these municipalities new waste water treatment plants are needed. At existing waste water treatment plants in the municipalities renovations are needed. New waste water treatment plants are needed for industry and livestock farming, and the efficiency of the others should be checked and probably improved.

If protection measures are directed to targets where efforts to decrease the phosphorus load have the greatest benefit, Scenario 2 could be reached with investments of 150 million USD. If production decreases with the closure of some enterprises, even less investments might be needed.

Table 11. Estimation of total phosphorus load according to different water protection measures and cost of water protection investments

Scenario	Total Phosphorus Load, t/a	Investment costs, mUSD
1	7400	0
2	5700	150
3	4000	450

4.5
Future Water Quality of Lake Ladoga

4.5.1
Basic Information for the Phosphorus Modelling Approach

The assessment of future water quality was based on the assumption that phosphorus is a key factor determining the level of eutrophication in Lake Ladoga.

Hydrological data and loading figures used in the application of lake phosphorus models are listed in Table 12. Explanation of the symbols used in Table 12; Lake Ladoga's catchment area divided into smaller subareas (A), runoff coefficients (q), mean flow from different subareas (Q), phosphorus loading from different subareas (L_p, unit tons of phosphorus per year) and mean total phosphorus concentrations of influent (C_i).

Table 12. Basic data from different sub-areas of the catchment area of Lake Ladoga. See text above for explanation of symbols.

Area	A km^2	q l/s·km^2	Q m^3/s	L_p t P/a	C_i μg P/l
Vuoksi	68,500	9.0	617	910	47
Svir	59,000	9.0	531	1,510	90
Volkhov	77,300	9.0	696	2,730	124
Syas	20,000	9.0	180	950	167
Other rivers	27,070	9.0	243	766	100
Non-point loading*	11,000	9.1	100	353	112
Islands	460	9.0	4	14	112
Precipitation	17,670	9.0	159	210	42
Sum/mean	281,000	9.0	2,530	7,443	93

*) Non-point loading from small rivers and direct drainage. Non-point loading entering the Ladoga via the Vuoksi, Svir and Volkhov rivers is included in rivers' figures.

Table 12 was created to check the overall validity of the data. It should be noted that simple lake phosphorus models applied later operate only with lake's total phosphorus loading and retention time (calculated by using total flow and lake volume). Therefore, the distribution of flow and phosphorus load of different sub-areas have no bearing on the final result of the models as long as the total loading and total flow (row "Sum/mean" on Table 12) remain the same.

Lake Ladoga's area is 17,670 km^2 with a mean depth of 51 m. the water volume is 908 km^3 and the average retention time is 11.5 years. The northern parts of the lake are deep, typically 50-100 m. The hypolimnion (water mass below depth 15-20 m) forms about 60-70 % of the total water volume.

4.5.2
Limnological Special Characteristics of Lake Ladoga

According to information provided by the Russian Institute for Lake Research the proportion of external phosphorus loading which is relatively permanently sedimented (phosphorus retention coefficient) in Lake Ladoga has shown slight indications of decline from 1981-1988 (Figure 8).

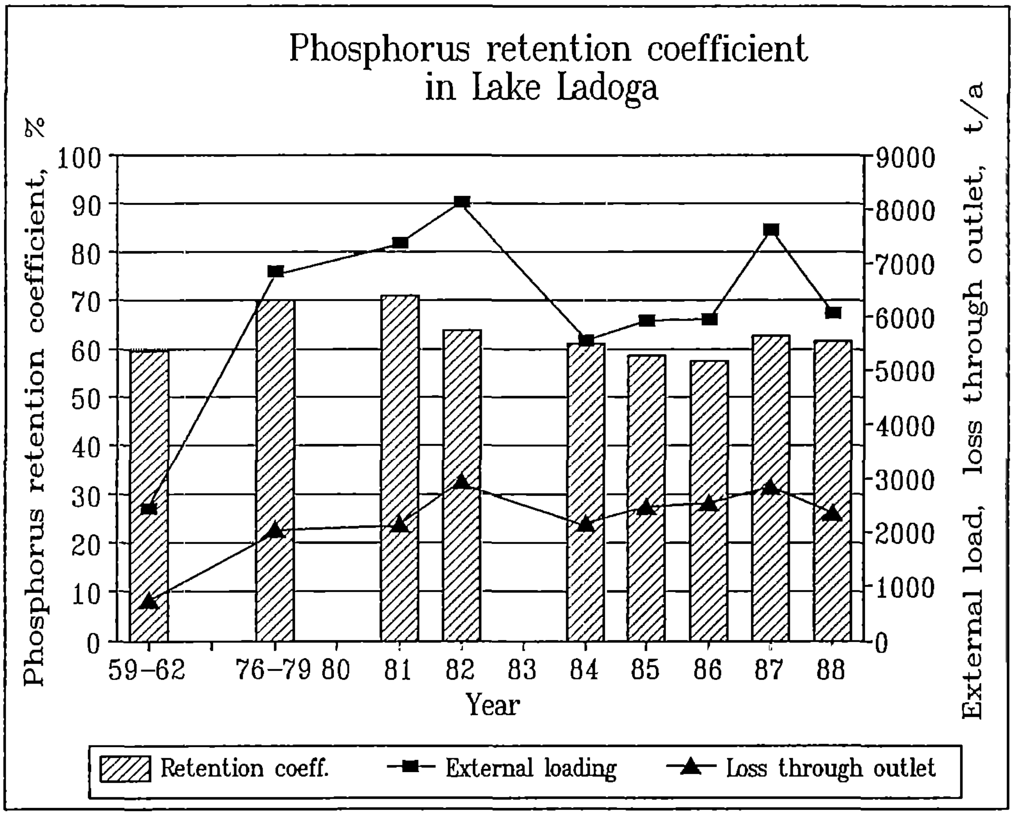

Figure 8. The external phosphorus loading, the phosphorus loss through the lake outlet and the sedimented proportion of external total phosphorus loading (phosphorus retention coefficient) in Lake Ladoga.

Ladoga's external phosphorus loading and sedimentation of phosphorus are considerably dependent on the drainage water flow which has significant yearly variations. Because of the long water retention time the sedimentation may react to changes in external loading with some delay time, and the sedimentation in certain years may be affected by the loadings from previous years. It can also be noted that phosphorus concentrations in Lake Ladoga did not increase from 1976-89, but instead concentrations have shown a slight decrease. It seems likely that the observed variations in the phosphorus retention coefficient indicate no deterioration in the state of Lake Ladoga.

The hypolimnion of Lake Ladoga has great volume because of lake's great depth and thus hypolimnion's storage capacity of oxygen is high. For practical purposes hypolimnion may be in this case defined as a water mass below the depth of 15-20 m. Ladoga's great depth also means that particulate organic matter is being effectively mineralized before it reaches bottom. The typical sinking velocity for particulate matter is 0.2-1 m/d, so it takes 50-200 days to reach the bottom to the pelagial parts of the lake.

Because of the great volume and depth the ice-covered period remains relatively short, but the lake has time to cool effectively in autumn. During the long and low-productive autumn period the production of new organic material is low and organic matter produced during the summer growing season has been transported to a great extent through the food chain to the consumer trophic levels where it has been transformed to carbon dioxide by the aerobic metabolism of the organisms. This property of effective decomposition of organic matter enhances Ladoga's ability to maintain good and productive conditions with loading levels greater than normal.

However, what has been said earlier does not concern relatively shallow and the most heavily loaded south eastern part of the lake, although Ladoga's horizontal currents and upwelling probably transport substances quite effectively to deeper areas.

Oxygen concentrations in the hypolimnion have been at an excellent level (over 10 mg/l) except in the south western parts of the lake and local heavily loaded bays.

The mean concentration of total phosphorus seems to be around 20-22 μg/l. According to data from 1988, 1990 and august 1993, without taking River Volkhov's area into account, late summer total phosphorus concentration is at epilimnion usually between 15-25 μg/l and in hypolimnion 13-20 μg/l.

Lower phosphorus concentration in hypolimnion compared to epilimnion seems to be most common situation. There may be at least three reasons for higher phosphorus concentrations in the epilimnion as follows: first, external loading is directed to the epilimnion. Second, the main part of internal loading originates from sediments from the shallow areas (<15 m) exposed to wind generated sediment re-suspension, and third, the vertical migration of the algae and zooplankton transport nutrients from deeper water masses to epilimnion. The epilimnion may be in Ladoga's case defined as the water mass between the surface and a depth of 15-20 m.

Hypolimnion with high oxygen concentration and bottom sediment acts as a sink for phosphorus which means that Ladoga's sediment is in good condition and will react rather well to a reduction in external loading, unlike more eutrophicated lakes suffering from low oxygen concentrations.

With more eutrophicated lakes suffering from oxygen depletion it is typical that no noticeable improvement can be found despite considerable a reduction in external loading. The reason for this is extensive internal loading, the most common case in highly eutrophicated lakes. Internal loading is defined as a flux or movement of substances, particularly phosphorus, from the bottom sediment back to the lake water.

4.5.3
Internal Phosphorus Loading

It's important to estimate the magnitude of internal loading, because it is an important factor affecting the high level of eutrophication when external loading is reduced. There are plenty of Finnish and international examples demonstrating that the level of eutrophication and nutrient concentrations don't by any means directly correlate with reductions in external loading.

Principles by which to calculate the lake's seasonal phosphorus balance have been presented by Lappalainen & Matinvesi (1990). The equations for calculation concerning a chosen time period, for example summer months, is as follows:

$$E+I = G+O+dM/dt$$

E = External phosphorus loading, kg/d
I = Internal phosphorus loading, kg/d
G = Gross sedimentation of phosphorus, kg/d
O = Output of phosphorus in effluent of the lake, kg/d
dM/dt = Change in the quantity of phosphorus in the lake water, kg/d

Internal loading can be calculated as remainder if all other variables are known by the following:

$$I = G+O+dm/dt-E$$

It must be mentioned that when internal loading is calculated as a remainder, as shown above, it's value is considerably dependent on the gross sedimentation's value which should be known. For example, if the gross sedimentation value has been estimated at 1,000 kg/d too high, internal loading will also be estimated at 1,000 kg/d too high. This indicates considerable potential error, especially in Ladoga's case, because the gross sedimentation hasn't been experimentally determined. In any case, the lake's internal processes must be considered when the effects of external loading changes are evaluated. In this work Ladoga's gross sedimentation has been estimated using values measured with the sediment trap method in other lakes. Results are presented in Figure 9 and Appendix 9.

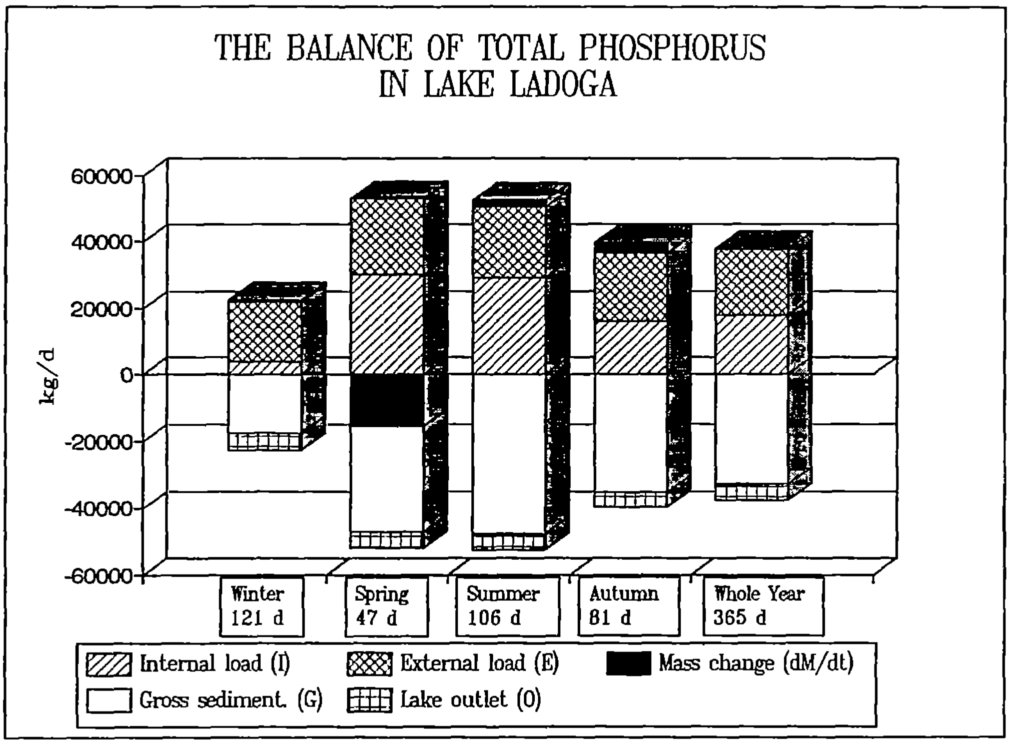

Figure 9. Ladoga's seasonal and annual total phosphorus balance.

On the basis of the total phosphorus balance it can be stated that net sedimentation is about 73 % of the external loading (annual mean value), which means that about 73 % of the total phosphorus entering the lake will be relatively permanent on the lake bottom. The magnitude of internal loading is about 0.87 times the external loading (annual mean value). This value may seem quite high, but it reflects the relatively good condition of the lake. In highly eutrophicated lakes the magnitude of internal loading may be over 10 times greater than external loading.

In summer the internal phosphorus loading estimate is roughly as great as the external loading. To confirm this the values of gross sedimentation should be determined experimentally in the future. With the use of reliable gross sedimentation values reliable internal loading values can be obtained. In absence of data the seasonal changes in the phosphorus concentration in the whole water column (dM/dt) have been approximated as relatively small.

The main conclusion from the calculations is that during the ice free period internal and external loading have both quantitatively as importance, in other words internal loading forms roughly half of the total circulation of the lake's phosphorus while external loading forms the other half. Presumably, relative reductions in external loading will be reflected in changes in the quality of the lake water by a magnitude which is only half the relative loading reduction. Despite the scientific limitations of this approach it suits the overall experimental data.

4.5.4
Lake Phosphorus Models

Ladoga's large water volume and long water retention time effectively smooth variations in external loading resulting in greater stability in water quality. Consequently, justifications for using simple models to deal with mean values for the whole year exist. On the other hand, simple lake phosphorus models found in literature are often constructed using data primarily from lakes smaller than Ladoga. Therefore, the applicability of a single model is not guaranteed and results must always be treated with caution. Ladoga's depth is exceptional so models based solely on depth are unsuitable.

The loading of the major three rivers is directed to the southern part of the lake, but during ice-free periods the anti-clockwise water mass circulation pattern induces relatively effective mixing conditions. Because of this river water with poorer quality does not particularly concentrate in the southern part of the lake. It was agreed to apply the models to Lake Ladoga as a one entity and no further areal division or separate areal application was made. During the period of ice cover there is no wind induced mixing and the areal differences in water quality are greater. During the period of ice cover the flow is partly governed by shoreline density currents which provide direct transit transport from the river mouths to the lake outlet, the pattern being considerably different than during the ice-free period. It was beyond the scope of simple phosphorus models to take the special features of winter time currents into account.

The effects of the internal loading phenomenon may be best explained by the lake ecosystem's resistance to change, however the delayed recovery must also be emphasized. On the other hand, high oxygen concentrations in Lake Ladoga and the sediment's probable good condition justify the assumption that internal loading wouldn't be very intense once external loading is reduced. For practical purposes it can be estimated that 50-70 % of the lowering of the phosphorus concentration predicted by simple phosphorus models will have a real effect. For example if annual mean phosphorus concentrations is presently 22 μg/l and the mean concentration after the loading reduction predicted by the model is 16 μg/l, the predicted lowering of concentration would be 6 μg/l. However, actual lowering would probably be 3-4 μg/l due to the effects of internal loading.

Several simple phosphorus models dealing with annual mean concentrations were evaluated for their applicability at Lake Ladoga (Table 13). One model, Lappalainen et al 1979, was calibrated using the estimate of present mean phosphorus concentrations (22 μg/l) and the present loading estimate.

Table 13. Mean phosphorus concentrations in Lake Ladoga with three loading scenarios (see paragraph 4.3) estimated by lake phosphorus models. Figures represent mean late summer total phosphorus concentrations.

Model	Scenario 1 (situation today)	Scenario 2	Scenario 3
Present situation according to data available	22	-	-
Chapra 1975	21	16	11
Kirchner & Dillon 1975	30	19	17
Lappalainen et al 1979, version calibrated for Ladoga	22	20	18
Larsen & Mercier 1976, version Q/A	33	20	18
Larsen & Mercier 1976, version Q/V	23	14	13
OECD 1982, version 1	19	15	12
OECD 1982, version 2	33	26	20
Reckhow 1977	21	17	12
Vollenweider 1976	21	16	12
Walker 1977	23	18	13
Mean value of the models	24.5	18.1	14.6

The mathematical expression of calibrated model Lappalainen et al (1979) is as follows:

$$C=\left\{1-\left[\frac{0.95\cdot(Ci-6)\cdot T}{3000+(Ci-6)\cdot T}\right]\right\}\cdot Ci$$

C = mean total phosphorus concentration in lake (μg/l)
Ci = mean total phosphorus concentration in influent of the lake = annual phosphorus load / annual water flow (μg/l)
T = water retention time (months)

Models Lappalainen et al 1979 (calibrated version), OECD 1982 version 1, Reckhow 1977 and Vollenweider 1976 seem to be the most suitable for predictive purposes in Ladoga's case, although the initial data available for comparison and checking the validity of the models is far from satisfactory.

Mean phosphorus concentrations changes can, on the basis of four chosen models, be roughly estimated as follows:

- In loading scenario 2 the mean phosphorus concentrations in the lake will be 17-20 μg/l (reduction 2-5 μg/l compared to the present mean concentration).
- In loading scenario 3 the mean phosphorus concentrations in the lake will be 14-18 μg/l (reduction 4-8 μg/l compared to the present mean concentration).

4.5.5
Tolerance of Phosphorus Loading

Methods for defining a lake's critical loading must be applied to Lake Ladoga with special caution because Ladoga has an excellent ability to maintain high oxygen concentrations in hypolimnion, but on the other hand Ladoga's ability to circulate nutrients may be very high. It has been known since 1950's that in late summer there are algal blooms consisting of diatoms, blue-green algae and green algae (Popov et al 1965). The level of nutrient circulation and eutrophication also depends on fish populations and their interaction with zooplankton and bottom sediments. Ladoga is exceptionally deep so the loading criteria based only on the lake area probably unsuitable.

Vollenweider published in 1968 a critical loading criteria which was based on the lake's area and mean depth. Though this criteria does not take water retention time into account, it may apply to Ladoga quite well. Figure 10 shows that at present loading in Lake Ladoga is in a state of mesotrophy. In this graphical presentation Ladoga is located between clear eutrophy and clear oligotrophy. It can also be noted that with loading scenarios 2 and 3 reduction in eutrophy is to be expected and according to Vollenweider's (1968) loading criteria scenario 3 even has the potential to change the lake's state into oligotrophy. In Figure 9 data from some Swedish, North American and Finnish lakes (source of data of other lakes is also presented: Granberg 1975).

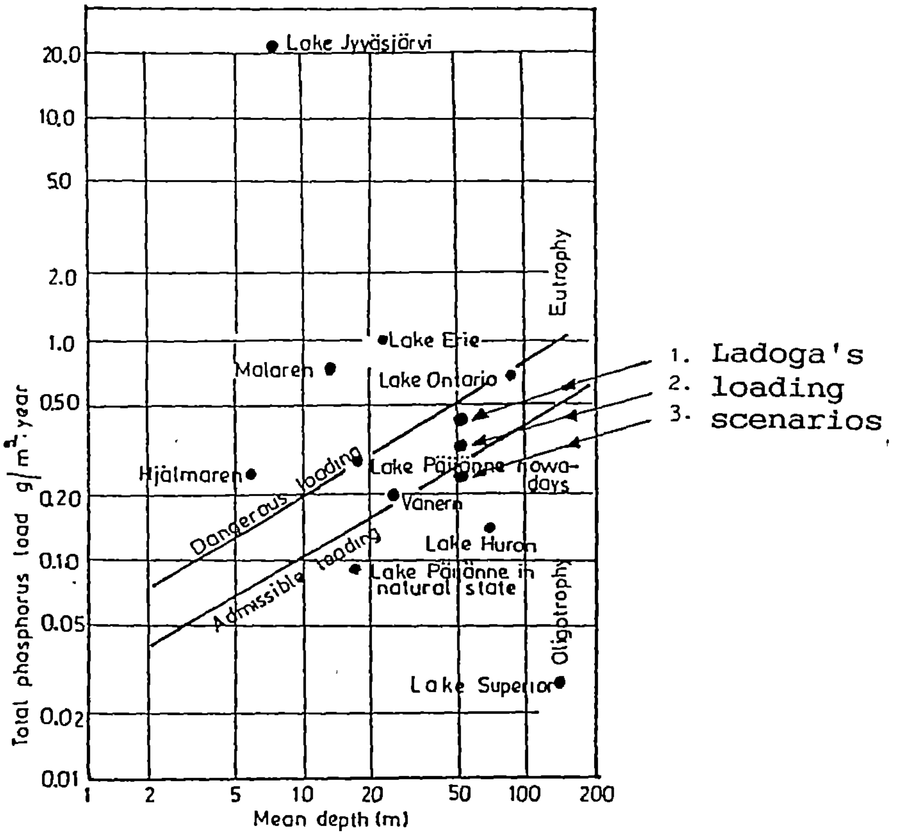

Figure 10. Phosphorus loading (areal loading) versus mean depth. Limits of oligotrophy and eutrophy according to Vollenweider (1968).

Vollenweider and Kerekes (1980) have presented a graphical method describing relationships between the lake's trophic categories and the average influent phosphorus concentrations, average lake phosphorus concentrations, average yearly chlorophyll concentrations and water residence time. Applied to Lake Ladoga this method shows decreasing eutrophication when loading decreases, but a clear oligotrophic state in the lake seems to be unobtainable even with a loading scenario as presented scenario 3 (Figure 11).

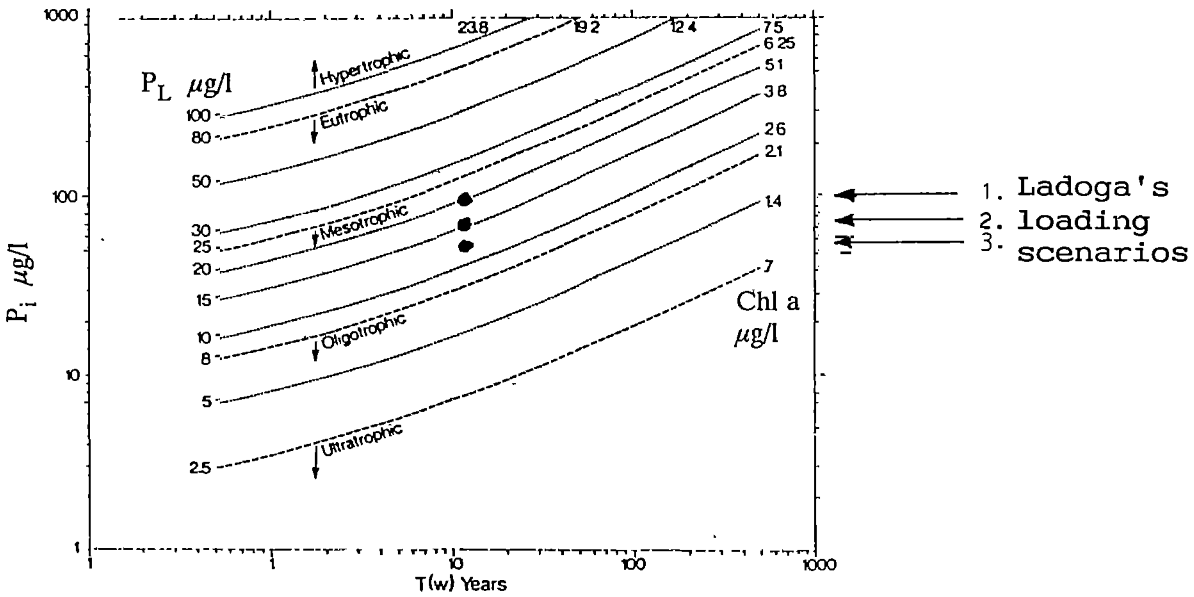

Figure 11. Relationships between the lake's trophic state, the lake's area and the water retention time (Vollenweider & Kerekes 1980).

Explanation of symbols in figure 11:

P_i = average influent phosphorus concentration (µg/l)
P_L = average phosphorus concentration in lake (µg/l)
Chl a = average annual chlorophyll-a concentration (µg/l)
T(w) = theoretical water retention time (years)

Petroca et al (1991, ref. Russian Institute for Lake Research 1993) have calculated that with a phosphorus loading of 7,000 t/a the lake may become eutrophic, and with 4,000 t/a the lake's state changes from the oligotrophy into mesotrophy. According to Vollenveider & Kerekkes, 1980 (see Figure 11) the phosphorus load should not be higher than 2,700 t/a to maintain oligotrophic state in the lake, but it could be even 10,000 t/a before the state changes to eutrophic.

By using Vollenweider's (1976) method for calculating critical loading and setting the highest permissible mean total phosphorus concentration at 20 µg/l, the highest permissible annual phosphorus loading would be 7,000 tons. According to Vollenweider's (1976) criteria loadings lower than this would prevent further eutrophication and keep Ladoga in a mesotrophic state and at most of its parts in relatively good condition.

4.5.6
Future Water Quality According to Different Scenarios

Scenario 1 (The 0-solution)

It seems likely that the present level of phosphorus loading somewhat exceeds the tolerance of Lake Ladoga and if loading is not reduced the lake's eutrophication will continue. However, no rapid changes are expected because of Ladoga's great mean depth, generally high oxygen concentrations even near the bottom, great water volume and long water retention time.

Present phosphorus loading is estimated at around 7,400-7,500 t/a. According to calculation methods presented by Vollenweider (1976) the loading level at 7,000 t/a would prevent Ladoga's further eutrophication (see paragraph 4.5.5).

Pollution of the lake will continue and its condition will slowly deteriorate. Negative changes will be most dramatic in the most polluted areas. The situation in the open lake and probably all over the lake stay fairly good because of the self purifying capacity of the huge lake.

Scenario 2 (The intermediate solution)

In this loading scenario Ladoga's mean phosphorus concentration is estimated to be around 17-20 μg/l. Compared to the approximate mean concentration of today, 22 μg/l, the lowering of concentration is 2-5 μg/l. With this change in mean phosphorus concentrations the state of the lake will in the long run change from eutrophy/mesotrophy to mesotrophy. Based on several mathematical equations[1] which describe the interdependence of total phosphorus concentration and chlorophyll-a concentration it can be estimated that in this scenario the average value of algal biomass in summer will decrease 10-30 percent compared to the situation today.

According to the theoretic calculation method presented by Chapra (1975) and Dillon & Rigler (1975) it takes 5-9 years to reach a new lower phosphorus concentration balance after loading has decreased permanently.

The water protection measures affect not only phosphorus loading, but also for instance loadings of nitrogen, biological oxygen demand and chlorinated organic compounds. The concentrations of these substances get lower especially in areas which are at present most polluted. Oxygen conditions will improve locally, especially in the heavily loaded bays with slow water exchange. The reduction of nitrogen loads are smaller than phosphorus reductions. Additionally changes in nitrogen loading may be partly counter-

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[1] References: OECD (1982), Ahl & Wiederholm (1977), Edmondson & Lehman (1981), Megard (1978), Jones & Bachmann (1976), Dillon & Rigler (1974), Schindler et al (1978), Sakamoto (1966).

balanced by changes in nitrogen fixation and denitrification activity. Nitrogen has anyhow less influence on eutrophication than phosphorus.

The reductions in BOD loading are likely to have no noticeable influence on overall water quality, because oxygen concentrations have been high in most parts of the lake. The reduction of the loading of chlorinated organic compounds will improve water quality in polluted coastal areas. Elsewhere the concentrations have not been particularly high.

Scenario 3 (The solution based on the mutual agreements between the Finnish Republic and the Russian Federation)

In this loading scenario Ladoga's mean phosphorus concentration is estimated to be around 14-18 μg/l. Compared to the approximate mean concentration of today, 22 μg/l, lowering the concentration is 4-8 μg/l. With this change in mean phosphorus concentrations the state of the lake will in the long run change from eutrophy/mesotrophy to mesotrophy. Compared to the intermediate solution scenario the improvement of water quality is somewhat better. Vollenweider's (1968) loading criteria even provides hope for Ladoga to return to the state of oligotrophy, but this is probably a little too optimistic an estimation. Based on several mathematical equations[1] described earlier it can be estimated that in this scenario the summer mean algal biomass will decrease by 20-40 % compared to the situation today.

The estimation of time delay between loading reduction and lowering of lake phosphorus concentrations is the same as in the loading scenario "Intermediate solution".

The effects of the water protection measures on substances other than phosphorus are similar to those in scenario 2. However, the tendency towards better water quality are likely to be somewhat pronounced because loading reductions are greater.

Water protection measures needed to achieve Scenario 3 should be taken are the minimum to ensure good raw water quality for water supply purposes in the future. Even further protection measures are highly recommendable, but they are either expensive or lead to production limitations for industrial enterprises. In the long run the target should be to again achieve an oligotrophic level for most parts of the lake.

5
ALTERNATIVE SOLUTIONS FOR WATER SUPPLY OF ST. PETERSBURG

5.1
Basis for the Comparison

5.1.1
Improvement of Raw Water

The present raw water quality should be improved to ensure the production of high quality potable water. In principle the raw water quality should be as good as possible. Groundwater would be the best alternative for good raw water, but the availibility of it for the total need of St. Petersburg is uncertain. Therefore surface water of as good a quality as possible should be used. The minimum demand for surface water should be the guiding principle, that no straight waste water discharges exist in the vicinity of the intakes. If improving the raw water quality is impossible, at least its treatment should be significantly improved.

In this study the following four alternatives for improving the raw water quality will be examined:

1. All straight waste water discharges to the Neva or its tributaries are collected and treated properly and the effluents transferred below the intake sites.
2. Raw water is transferred from a clean part of Lake Ladoga.
3. Raw water is transferred from the upper course of the Vuoksi.
4. Natural groundwater is collected from eskers and the water yield from them increased by artificial groundwater.

5.1.2
Improvement of Water Treatment and Distribution

At the moment the total capacity of the main five existing water treatment plants is about 3,050,000 m^3/d. Compared to water demand the capacity should be about 450,000 m^3/d greater. If efforts to decrease water consumption in St. Petersburg succeed, the necessity for extra capacity becomes at least less urgent.

At present good potable water quality cannot be maintained at all times. Improvement of water quality is very expensive, because of the huge volumes needed for purification. Anyhow health risks should be avoided, so as good a water as possible should be distributed, at least for drinking and cooking purposes.

If water is taken from the Neva, water treatment processes should be intensified. To prevent adverse effects from storms at Lake Ladoga it would be reasonable to build a raw water reservoir which would be large enough to cover one week's water demand. This would help maintain the quality of distributed water.

Only minor changes to the present prosesses would be needed, if the water from Lake Ladoga was used. The transfer distance to St. Petersburg is one third distance to the upper course of the Vuoksi.

Should the present water demand be covered the construction of a transfer system to the upper course of the Vuoksi or collection of groundwater would be very expensive. If water consumption were decreased for instance to the level of western countries (about 300 l/cap/d) or water for drinking purposes was distributed separately, Lake Ladoga and Vuoksi River alternatives would be more attractive.

The demand for cleaner and more expensive potable water for drinking and cooking in St. Petersburg would be about 15,000 m^3/d (3 l/cap/d) and together with other water requirements it would probably stay below 100,000 m^3/d. This amount might be covered even by groundwater, which possibly could be distributed after only an alkalization process.

5.2
Neva River as a Raw Water Source

5.2.1
Raw Water Quality

The present mean water quality of the Neva close to the intake site at SWTP is as follows:

-	P	27	µg/l
-	N	2000	µg/l
-	COD_{Mn}	8	mg/l
-	pH	7.4	
-	alkalinity	0.5	meqv/l
-	faecal coliform bacteria	1400	/100 ml

These figures describe the raw water quality of NWTP and VWTP as well. Raw water quality of MWTP and PWTP is worse especially with respect to bacterial quality.

If the Neva is used as raw water source in the future, water quality should be improved and the efficiency of water treatment significantly increased. In addition, all straight waste water discharges from the suburbs of St. Petersburg and along the Izora river should be collected, biological treatment plants built and their effluents led downstream from the water intake sites.

Otherwise the concentrations of faecal micro-organisms will stay at so high a level that the risk of waterborne diseases will increase. Other contamination might cause other problems for instance with taste and odour.

Waste waters which are discharged to the Neva most directly affect water quality close to the river banks. Raw water for water treatment is taken from the main stream. Raw water for MWTP and PWTP should be transfered from the area which SWTP uses or even upstream. If raw water intakes are moved upstream from the mouth of the Izora, needed emergency investments for waste water collection and treatment would decrease.

Petrokrepost Bay (outlet of Lake Ladoga) is reported to be one of the most polluted areas in Lake Ladoga and therefore the water quality along the Neva cannot be classified as good. This is one of the reasons why investments in waste water treatment even within the water catchment area of Lake Ladoga should be considered in any case.

If nothing is done to decrease the waste water load to Lake Ladoga and the Neva (Scenario 1), water quality will remain at a poor level or get even worse. Scenario 2 would probably make the microbiological quality better. According to Finnish criteria the raw water would probably stay at a satisfactory level because of the algae and maximum temperature. Nothing can be done to maximum temperature, but otherwise a good level might be reached through the operations described in Scenario 3.

Factors keeping the raw water quality at a lower level are mainly related to waste water discharges into the Neva, thus the protection measures of Lake Ladoga are less urgent.

During and after storms on Lake Ladoga turbidity and the concentration of suspended solids rises remarkably affecting the level of turbidity in distributed water. Because many more serious issues related to decreasing water quality are related to turbidity, it might be reasonable to construct an artificial reserve for raw water.

5.2.2
Needed Investments for the Protection of the Raw Water Source

To improve the raw water, waste water loads into Lake Ladoga and the Neva should be decreased to the level described in Scenario 3. Special attention should be paid to waste waters which are discharged into the Neva, its tributaries or Petrokrepost Bay.

Within this report only little attention could have been paid to straight loading into the Neva and its tributaries. They should be investigated in further projects. The main portion of waste water is discharged into the river within the borders of St. Petersburg. Waste water from about two million inhabitants is discharged into the river between SWTP and MWTP. At present raw water from SWTP is not good, but its micro-biological quality is much better than in MWTP. About 300,000 people live along the Izora and about the same amount of pigs are bred. The waste waters from these sources are unsatisfactorily treated. That is why the river is heavily polluted. The same issues apply to the Slavyanka which discharges into the Neva quite near the raw water intake of SWTP.

5.2.3
Needed Investments for Water Supply

A 450,000 m^3/d water treatment capacity together with the needed capacity (100,000 m^3/d) to withdraw the Petrogradsky Water Treatment Plant should be built. The capacity of the Main Water Treatment Plant (705,000 m^3/d) should be rebuilt in the vicinity of STWP or even upstream along the Neva. The other possibility is to take raw water from the same area as SWTP and to transfer it to the existing MWTP. An artificial lake as a raw water reserve must be constructed to maintain water quality during storms, otherwise the filtration capacity should be increased.

At present raw water is treated by chemical flocculation, filtration and chloramine chlorination. Under certain circumstances only part of the water volume is flocculated (see chapter 1). The dosing of flocculants decreases the pH, which is adjusted to a suitable level by dosing soda or by mixing flocculated and unflocculated waters.

The purification practice should be changed so that all water is treated by adequate amounts of flocculants. It is needed for the removal of organic material inclueding bacteria, viruses and other microfauna. Contact filtration as a treatment process is not as effective as separate flocculation, sedimentation and filtration. All of the raw water should be filtrated through sand and activated carbon filters and the planned surface loads should not be exceeded. The level of the pH should be raised to 8 through alkalization. Chlorination should be improved to ensure the microbiological quality of water. Also, present water treatment processes should be renovated. The required process units are described in Table 15:

Table 15. Required water treatment process units for taking raw water from the Neva River

Alternative	Process
The Neva as raw water source, effective treatment for all waste waters (final situation by Scenario 3)	flocculation (carbon dioxide dosing) sedimentation filtration chlorination (1 activated carbon filtration chloramine chlorination alkalization

(1 If water quality stays as it is today ozonation would be needed instead of chlorination.

Ozonation would be more effective against bacteria, viruses and other microfauna than chlorination. It also removes the unpleasant taste and odour caused by the algae in raw water. It is anyhow so expensive that its use is presently unrealistic. If raw water quality does not improve soon, ozonation is highly recommendable.

At present distributed water is corrosive. The corrosion deteriorates the water quality, increases pipe damages and decreases the capacity of pipes (increases incrustations in the pipes). When all water is treated with chemical precipitation, post alkalization is essential. The cheapest and the easiest way to facilitate alkalization is the use of lime ($Ca(OH)_2$). Alkalinity will be about 0.5 meqv/l, if 13 g/m^3 lime is used. This is however not quite enough to minimize the corrosion risk of the network. The corrosion risk is smaller if soda ash (Na_2CO_3) is used. Another, most recommendable alkalization alternative is the usage of carbon dioxide (CO_2) with lime. To reach the target alkalinity 0.7 meqv/l, the dosage of carbon dioxide should be about 9 g/m^3 and the dosage of lime about 21 g/m^3.

All water treatment plants in St. Petersburg use chloramine chlorination for disinfection. To obtain the same disinfection efficiency as with free chlorine, 100 times more contact time is needed. For example to achieve 99 per cent illimination of faecal coliforms with free chorine, the contact time needed is about 2 minutes and with monochloramine 200 minutes (3.3 hours).

The normal concentration of chloramines or even free chlorine in drinking water is not effective against micro-organisms often found in distribution systems. Both free chlorine and chloramine are more effective against common indicator bacteria (for example faecal coliforms) than many more dangerous bacteria and viruses. That is why the lack of faecal coliforms in the drinking water do not mean perfect hygiene in the water.

5.2.4
Cost Estimates

Estimated investment costs according to minimum required measures are as follows:

- water pollution control in Lake Ladoga (Scenario 3)	450 million USD
- renovation of existing water treatment plants	300 million USD
- construction of additional 550,000 m^3/d	80 million USD
- raw water transfer from intake of SWTP to MWTP	30 million USD

In this study only a little attention could have been paid to water pollution control measures for the Neva and its tributaries. Therefore no cost estimate has been given for them.

Renovation of existing water treatment plants include new activated carbon filtration and alkalization units as well as renewal of old process units. If raw water was taken above the mouth of the Izora, the rough cost estimate for the transfer system would be about 90 million USD. A raw water reservoir with a retension time of a week would be one solution to secure good raw water quality at all times. This would mean a volume of at least 25 million m^3. The rough cost estimate for the excavation of this reservoir is 50 million USD. A water transfer system for the present raw water intakes would cost about 120 million USD.

The estimated additional annual running costs caused by the use of treatment chemicals are 19 million USD higher than today.

5.3
Lake Ladoga as a Raw Water Source

5.3.1
Raw Water Quality

Because of the present poor water quality of the Neva River, it might be reasonable to transfer cleaner raw water to the water treatment plants of St. Petersburg from Lake Ladoga. Because the best water quality would come from the upper part of hypolimnion, the best intake depth would be 10 to 15 meters, when the total depth is 15 to 20 meters.

According to a preliminary map examination a suitable location for the beginning of inlet suction tunnel would be about 7 km north of Volojarvi Lake and 8 km from the bank of Lake Ladoga (see Figure 12). Water quality around the proposed intake site is one of the best in Lake Ladoga. A couple of samples taken and analyzed by Finnish authorities are available. According to them the present water quality is as follows:

-	P	13 $\mu g/l$
-	N	580 $\mu g/l$
-	COD_{Mn}	7.2 mg/l
-	pH	7.8

According to Finnish criteria this raw water can be classified as good.

Water depth is over 10 meters even 2 km from the bank of Lake Ladoga. Therefore the need for a 8 km long inlet suction tunnel should be checked.

5.3.2
Needed Investments for the Protection of Raw Water Source

If nothing is done to protect the quality of Lake Ladoga (Scenario 1), the value of the Lake as a raw water source will slowly get worse. Water from the Vuoksi in particular can occasionally harmfully effect the water quality at the planned intake area.

Water quality will begin to improve with the phosphorus and waste water load decreases mentioned in Scenarios 2 and 3. Scenario 3 is more recommendable because it affects the water quality of the whole lake. If pollution control measures were directed to the targets as a highest priority, with respect to the planned intake site, good results could be reached even with Scenario 2.

Investments in waste water collection and treatment along the Neva and its tributaries are still urgent because construction of the transfer system takes several years. If time is not taken into consideration, only those water protection measures which are related to Lake Ladoga will be important. Because the prevailing current from the Vuoksi is directed towards the water intake site, the most important water protection targets are waste water from the Svetogorsk pulp and paper mill and non-point pollution to the Vuoksi. Purification of waste waters from the Volkhov aluminium plant is very cost effective as well.

5.3.3
Needed Investments for Water Supply

The guiding principles for the plan of water transfer is presented in Figure 12:

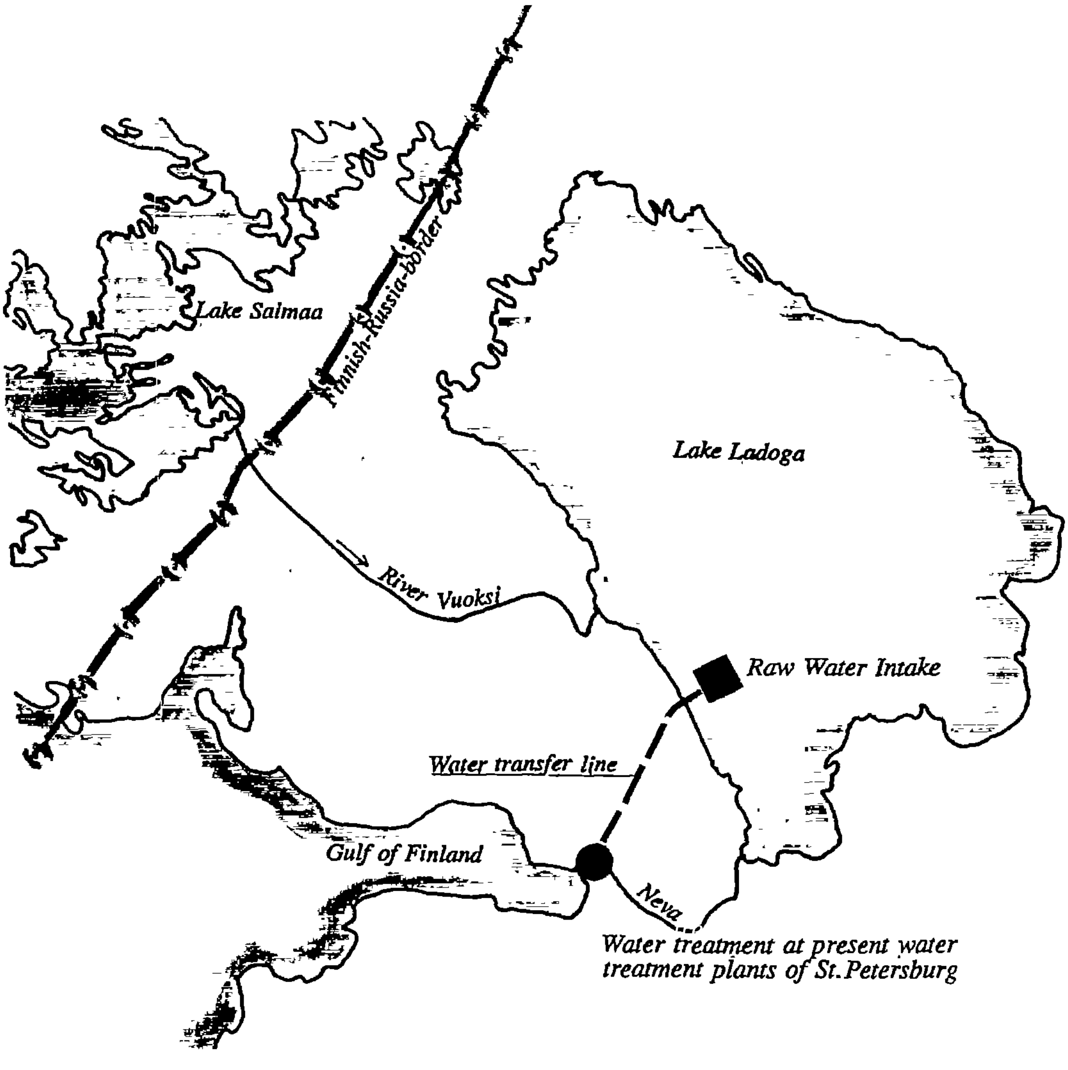

Figure 12 Alternative, where raw water is transferred from Lake Ladoga to St. Petersburg

The soil in the area consists basically of gravel and sand deposits outside eskers. Therefore, excavation of a transfer line would probably be easy. The system could be as follows:

- inlet suction tunnel (40 m^2, 8 km)
- intake pumping station (lifting height 20 m)
- intermediate pumping station (lifting height 40 m)
- open channels (130 m^2, total length 63 km)
- tunnels or several parallel pipes under pressure (total length 16 km)

The water should be transferred to existing water treatment plant raw water intakes. To secure the raw water quality it is reasonable to cover the channels.

As long as surface water is used as a raw water, existing water treatment plants should be renovated and alkalization units added to the treatment process. A 450,000 m^3/d water treatment capacity together with the needed capacity (100,000 m^3/d) to withdraw the Petrogradsky Water Treatment Plant should be constructed. The required process units are described in Table 16:

Table 16. Required water treatment process units if raw water is taken from Lake Ladoga

Alternative	Process
Lake Ladoga as raw water source (Scenarios 1, 2 and 3)	flocculation (carbon dioxide dosing) sedimentation chlorination filtration chloramine chlorination alkalization

If a delay in the construction of the transfer system is taken into account, active carbon filtration units for water treatment plants would be required. Otherwise they would be necessary only for water protection Scenario 1 (0 - solution), and even in this case not until later.

5.3.4
Cost Estimates

Estimated investment costs according to the minimum required measures are as follows:

- water pollution control in Lake Ladoga (Scenario 3)	450 million USD
- renovation of existing treatment plants	50 million USD
- construction of additional 550,000 m^3/d	50 million USD
- water intake and transfer system	480 million USD

Without further investigations it is impossible to provide anything other than a rough cost estimate for the water transfer system.

The costs of treatment chemicals would stay at the present level if dosing of carbon dioxide is not needed. If alkalinity is so low that carbon dioxide dosing is needed, additional annual costs will be 6.6 million USD. The estimated annual pumping costs of raw water are 13 million USD.

5.4
River Vuoksi as a Raw Water Source

5.4.1
Raw Water Quality

Because of the good water quality at the upper course of the Vuoksi it has been proposed that raw water for St. Petersburg be transferred from there. The present water quality on the Finnish side of the border is as follows:

- P	8	μg/l
- COD_{Mn}	7	mg/l
- N	500	μg/l
- pH	7	
- alkalinity	0.17	meqv/l

There are plans to collect purified waste water which has been discharged into the southern part of Lake Saimaa and transfer it to the Vuoksi. This is proposed first of all as a water protection measure to improve the water quality of Lake Saimaa, but in case the effluent is discharged in the neighbourhood of Svetogorsk (Russian side) the quality of the water, which has been planned for transfer, will improve.

5.4.2
Needed Investments for the Protection of Raw Water Source

Investments in waste water collection and treatment along the Neva and its tributaries are still urgent because construction of the transfer system takes several years. If time is not taken into consideration only minimal investments in waste water treatment for the Russian part of the Neva catchment area are needed. Waste water effluents from Svetogorsk as well as those collected and treated in Finland should be discharged into the Vuoksi below the intake site.

5.4.3
Needed Investments for Water Supply

The distance from Svetogorsk to St. Petersburg is about 170 kilometers. According to a preliminary map examination the first 60 km are estimated to consist of solid rock which is not too deep under ground. There the construction of a tunnel would be fairly easy. Along the last 110 km solid rock is obviously at a depth of over one hundred meters. Therefore it is proposed that the later part of the transfer system be constructed in open air. The soil is made up of gravel or sand along most of the area. The potential plan is presented in Figure 13.

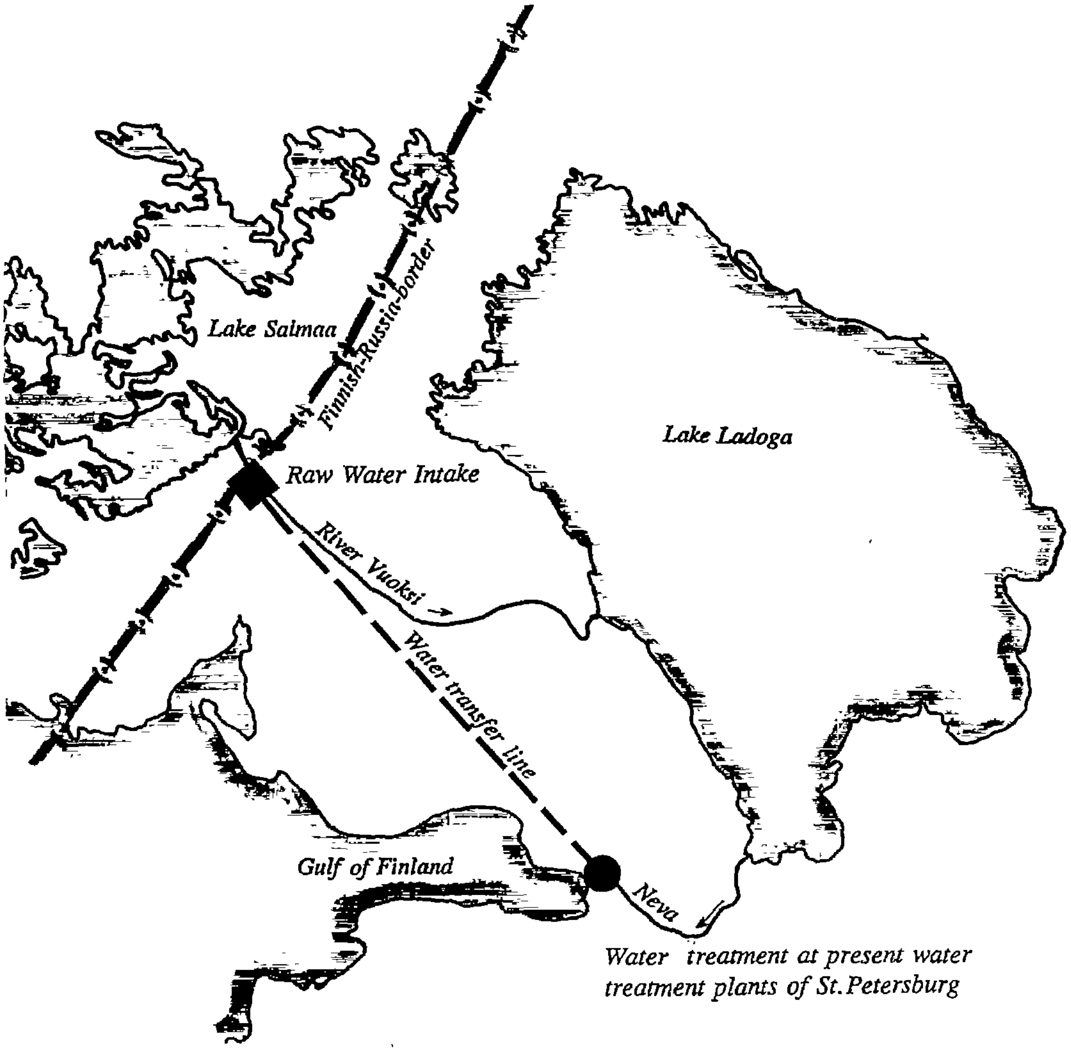

Figure 13 Alternative, where raw water is transferred from the upper course of the Vuoksi River to St. Petersburg

If the present raw water need for St. Petersburg will be transferred, the system consists of the following units:

- tunnel in rock (60 m^2, 60 km)
- open channels (130 m^2, total length 80 km)
- transfer tunnels under pressure (40 m^2, total length 30 km)
- four pumping stations (total lifting height 70 m)

Needed water treatment process units are the same as in Lake Ladoga case.

If water consumption could be decreased to 300 l/cap/d, which is quite normal level in western countries, needed water amount to be transfered would be about 1,500,000 m^3/d. In this case only one third of the transfer system dimensions are needed.

5.4.4
Cost Estimates

Estimated investment costs according to minimum measures needed are as follows:

-	water protection measures in River Vuoksi	40 million USD
-	renovation of existing water tretment plants	50 million USD
-	construction of additional 550,000 m^3/d	50 million USD
-	water intake and transfer system	760 million USD

Without further investigations it is impossible to give other than rough cost estimate of the water transferring system. If water amount to be transfered were only 1,500,000 m^3/d, the investment cost of water intake and transfer system would be about 380 million USD.

Estimated additional running costs caused by the the need of carbon dioxide dosing are 6.6 mUSD/a higher than today. Estimated pumping costs of raw water are 15 mUSD per year. In further investigations the cost balance between needed pumping and dimensions and height differences of the transfer line should be optimized.

5.5
Separate Drinking Water Supply

High quality water is needed at least for drinking and cooking purposes. Separate supply of it might be a competitive alternative, because of the following reasons:

- needed investments in water treatment plants are huge, if all water should be treated as it were for drinking
- to be able to maintain good water quality continuously huge investments are needed in water distribution system
- markets for bottled water are growing and the market price of water is high

When the living standard in St. Petersburg rises, more value will be paid for the good quality of drinking water. The cheapest store price of bottled water in Finland is about 0.5 dollars per liter. The need for drinking and cooking is about 3 l/cap/d. If all this were covered by bottled water, the needed water amount in St. Petersburg would be 15,000 m^3/d and the annual costs for it 2,700 mUSD. In addition some industrial enterprises need good water quality to their processes or products and some hotels and individuals are willing to fulfil their whole need of water with higher water quality.

Because the length of pipes in the present distribution system is over 10,000 km when pipes within the houses are excluded, it is impossible to to build a parallel distribution system for a cleaner water to all consumption points.

Instead the main part of water could be sold from special water kiosks and from water tanks to customer containers.

If waters for drinking and other uses will be separated, the raw water for drinking water should be as good as possible, usually groundwater. Groundwater has also the best protection against pollution. There are some remarkable eskers within the radius of 80 km from St. Petersburg and at least minor volumes of groundwater can be reached even closer than them. The quality and quantity of available groundwater should be investigated and the risks for water quality eliminated at groundwater infiltration areas.

According to a map examination 15,000 m^3/d groundwater could easily be taken even from the closest esker by Lake Ladoga. If the water yield of this esker is unsufficient, it could be increased by bankfiltration, by making of artificial groundwater or by transferring water from other eskers like presented in Figure 14. If transfer system described in Figure 14 were used, yields up to 200,000 m^3/d might be able to be reached.

If the quality of groundwater is as good as supposed, it could be distributed to customers after alkalization and possibly chlorination.

A rough estimate for the investment costs of transfer system from the closest esker near Lake Ladoga to one point in St. Petersburg is 15 mUSD. Compared to the market price of bottled water it can be considered as a minimal costs.

Figure 14. Alternative, where groundwater is collected from eskers closer than 80 km to St. Petersburg

6
COMPARISON OF ALTERNATIVES

A summary of estimated present and future water quality in different raw water alternatives is presented in Table 17. The estimated future water quality can be reached by implementing the following water protection measures:

- Neva River: Within catchment area of the Neva above the raw water intakes for Scenario 3. In addition, the treated waste water effluents must be discharged below intake sites.
  Within the catchment area of Lake Ladoga at least Scenario 2.
- Lake Ladoga: Scenario 3 within the catchment area of Lake Ladoga.
- Vuoksi River: Treated waste water effluents from Southern Saimaa and Svetogorsk will be collected and discharged below the intake site.

These water protection measures should be taken as a recommended minimum. Construction of water transfer systems for raw water alternatives from Lake Ladoga and the Vuoksi will take several years, although the financing for the projects is available. Therefore, waste water collection and treatment above the present raw water intakes must be improved and effluents discharged below them whatever the final raw water alternative is. In addition to this the existing water treatment processes should be significantly intensified.

If raw water is taken either from the Neva or Lake Ladoga the protection of Lake Ladoga plays a very important role. If water is transferred from the upper course of the Vuoksi, only those water protection measures which are taken for the upper course of the Vuoksi will effect the raw water quality. The cost estimate for these measures is about 40 mUSD. Estimated costs for water protection measures within the catchment area of Lake Ladoga are as follows:

- Scenario 1	0 mUSD
- Scenario 2	150 mUSD
- Scenario 3	450 mUSD

Table 17. Estimated present and future raw water quality

		Raw Water Quality of Alternative Sources		
		River Neva	Lake Ladoga	River Vuoksi
Present	P_{tot} µg/l	27	13	8
	N_{tot} µg/l	2,000	580	500
	COD_{Mn} mg/l	8	7.2	7
	pH	7.4	7.8	7.0
	alkalinity meqv/l	0.5	0.5	0.17
	faecal coli /100ml	1,400	none	occasionally some
	mineral oils µg/l	50	< 20	< 20
	colour	30	30	30
EU recommendation for the treatment process		intensified	existing	existing
Finnish raw water class		unsuitable	good	good
Future	P_{tot} µg/l	14-20	10	7
	COD_{Mn} mg/l	7	7	6
	faecal coli /100ml	occasionally	none	none
	mineral oils µg/l	< 20	< 20	< 20
	colour	30	30	30
EU recommendation for the treatment process		existing	existing	existing
Finnish raw water class		good / satisfactory	good	good

A summary of needed water treatment process units for different raw water alternatives is presented in Table 18.

After renovation measures at the treatment plants have been completed the quality of distributed water will improve significantly (for instance the risk of waterborne diseases decrease). Anyhow the quality of potable water has a strong correlation to the conditions in the distribution system. Because they were not examined in this study, it would not be relevant to give exact estimates concerning water quality at different consumption points in the water distribution system.

Table 18. Needed process units for water treatment plants

Alternative Source for Raw Water	Process
River Neva collection and treatment for all waste waters discharged into River Neva or its tributaries ozonation is needed if water is not taken above waste water effluents	flocculation (carbon dioxide dosing) sedimentation filtration chlorination (or ozonation) activated carbon filtration chloramine chlorination alkalization
Lake Ladoga activated carbon filtration might be needed, because the construction of the transfer system takes time	flocculation (carbon dioxide dosing) sedimentation chlorination filtration chloramine chlorination alkalization
Upper course of River Vuoksi activated carbon filtration is needed, because the construction of the transfer system takes time	flocculation carbon dioxide dosing sedimentation chlorination filtration chloramine chlorination alkalization

Rough estimates for investment costs of different alternatives are presented in Table 19 and additional maintenance costs in Table 20. The cost of ozonation is not taken into account in for the Neva nor is activated carbon filtration for Lake Ladoga and the Vuoksi. A comparison of annuity costs which have been calculated according to figures presented in Appendix 11, is provided in Table 21.

Table 19. Investment costs related to water transfer and treatment for different raw water alternatives

Subproject	Alternative Raw Water Sources		
	River Neva	Lake Ladoga	River Vuoksi
Construction of raw water transfer system	3) 30 mUSD 4) 120 mUSD 5) 170 mUSD	480 mUSD	760 mUSD
Renovation of present water treatment plants (1	300 mUSD	50 mUSD	50 mUSD
Construction of extra capacity (2	80 mUSD	50 mUSD	50 mUSD
Total	3) 410 mUSD 4) 500 mUSD 5) 550 mUSD	580 mUSD	860 mUSD

1) Excluding Petrogradsky Water Treatment Plant
2) Including the withdrawal of Petrogradsky Water Treatment Plant
3) Raw water is transferred to an intake of MWTP from an intake of SWTP
4) Raw water to all intakes is transferred above the mouth of the Izora river
5) Raw water reservoir for 7 days retention time is excavated and raw water is transferred from there to WTP intakes

Table 20. Additional annual maintenance costs related to water transfer and treatment for different raw water alternatives

Subproject	Alternative Raw Water Sources		
	River Neva	Lake Ladoga	River Vuoksi
Pumping of raw water	1) 0.9 mUSD/a 2) 3.0 mUSD/a 3) 3.7 mUSD/a	12.7 mUSD/a	14.8 mUSD/a
Additional need of chemicals	19 mUSD/a	0 mUSD/a	6.6 mUSD/a
Total	1) 20 mUSD/a 2) 22 mUSD/a 3) 23 mUSD/a	13 mUSD/a	21 mUSD/a

1) Raw water is transferred to an intake of MWTP from an intake of SWTP
2) Raw water to all intakes is transferred above the mouth of the Izora River
3) Raw water reservoir for 7 days retention time is excavated and raw water transferred from there to WTP intakes

Table 21. Comparison of annuity costs related to tables 19 and 20

Subproject	Alternative Raw Water Sources		
	River Neva	Lake Ladoga	River Vuoksi
Construction of raw water transfer system	3) 2 mUSD/a 4) 8 mUSD/a 5) 12 mUSD/a	34 mUSD/a	54 mUSD/a
Pumping of raw water	3) 1 mUSD/a 4) 3 mUSD/a 5) 4 mUSD/a	13 mUSD/a	15 mUSD/a
Renovation of present water treatment plants 1)	26 mUSD/a	4 mUSD/a	4 mUSD/a
Construction of extra capacity 2)	8 mUSD/a	4 mUSD/a	4 mUSD/a
Additional need of chemicals	19 mUSD/a	0 mUSD/a	7 mUSD/a
Total	3) 56 mUSD/a 4) 64 mUSD/a 5) 69 mUSD/a	55 mUSD/a	84 mUSD/a

1) Excluding Petrogradsky Water Treatment Plant
2) Including the withdrawal of Petrogradsky Water Treatment Plant
3) Raw water is transferred to an intake of MWTP from an intake of SWTP
4) Raw water to all intakes is transferred above the mouth of the Izora river
5) Raw water reservoir for 7 days retention time is excavated and raw water transferred from there to WTP intakes

The quickest improvements can be reached by renovating existing treatment plants. Some of the renovations are essential in any case. According to Table 21 Lake Ladoga seems to be the cheapest alternative as a raw water source. Anyhow there might be technical difficulties in the construction of the transfer system which was not taken into account in this preliminary examination. Besides, the construction of the water transfer system would take at least 10 years and immediate intermediary measures should be taken. If costs related to this period of transition were taken into consideration, the Neva would probably be the most attractive alternative for a period of 30 years.

Storms in Lake Ladoga as well as melting snow make the quality of the Neva much worse than normal which has harmful effects on potable water quality. An artificial water reservoir would help prevent these effects, but the required basin volume is so huge that it may be difficult to find a suitable location for it. Excavation of a reservoir to fulfil one week's water needs would cost about 50 millon USD and a water transfer system to the water treatment plants would be roughly 120 million USD. If these investments or water transfer above the mouth of the Izora river are included in the investment programme, annual costs of the Neva alternative will increase by about 13 or 8 million USD/a.

Measures to improve the raw water quality are most urgent and most expensive as in the case of the Neva, where raw water is used as the source, but most of these measures should be done in any case to fulfil international water protection agreements.

For the Neva alternative the most significant waste water point-sources which have greatest effect on water quality are along the Neva and its tributaries. If water is taken from Lake Ladoga it is taken from along the Volkhov river and especially along the Vuoksi. With respect to the Vuoksi alternative, waste water loads could be eliminated easily. However, the total costs are higher than in the other two alternatives.

Phosphorus loads to Lake Ladoga should not exceed 7,000 t/a to keep it at the present level of eutrophication. This requires some decrease in present load. If the target is to achieve the ecological balance which existed before anthropogenic eutrophication (oligotrophic state), the phosphorus load should be decreased at least by 50 % which requires even greater reductions than described in Scenario 3 (see chapter 4.5.5).

From the point of view of health risks the Neva is the worst alternative, but if the Neva's microbiological quality and water treatment were improved no significant differences between different alternatives could be found.

The more phosphorus and other pollution loads to Lake Ladoga will decrease proportionately to an increase in its fishing and recreation value. Pathogens of effluents to River Neva should be reduced to secure fishing, recreation and raw water value.

7
FINDINGS AND CONCLUSIONS

There are technical, aesthetic and even hygienic problems with potable water from St. Petersburg. Taste, odour, turbidity, colour, iron, manganese, aluminium, ammonia, pH balance, organic chlorine compounds and micro-organisms occasionally reach unsuitable levels. Treated water has anyhow fulfilled national GOST norms.

The Neva River is heavily polluted with waste water. The high content of faecal micro-organisms, oil products and nutrients are the greatest deterants to its suitability as raw water. Additionally, storms on Lake Ladoga can significantly increase the concentration of suspended solids. Nevertheless, within a few years the Neva seems to be the only realistic option as the main raw water source for St. Petersburg. It would take a long time before other water alternatives could be used for the production of potable water.

To improve the quality of potable water the following immediate measures are proposed for water treatment plants:

- all water should be treated with adequate amounts of flocculants
- disinfection should be intensified
- treated water should be alkalized

Water treatment capacity should be increased by 450,000 m^3/d, if water consumption cannot be quickly decreased. The raw water to existing water treatment plants is taken from five different intakes two of which sustain water qualities which are occasionally quite poor. These two intakes and/or the treatment plants should be rebuilt at a better location along the river. The direct waste water discharges to the Neva above the intake sites should be diverted and proper waste water treatment plants constructed for them. The effluents from waste water treatment plants should be transferred downstream from the intake sites.

To ensure the raw water quality of St. Petersburg the targets mentioned in the mutual water protection action plan between Finland and the Russian Federation are necessary and urgent. Because of the enormous size of Lake Ladoga, major parts of it are still in fairly good condition. Areas around the mouths of the main rivers and the surroundings of some municipalities and industrial enterprises are however heavily polluted. The shallow southern part of the lake, to which the greatest nutrient loads are directed, is the most eutrophicated. This has a direct relation to the water quality of the Neva.

Within the catchment area of Lake Ladoga the greatest phosphorus point-sources, the Volkhov aluminium plant and Svetogorsk pulp and paper mill, as well as the non-point load from agriculture, are the most urgent priorities in preventing further eutrophication of the lake. Livestock farms are in a key position as well. Savings from fertilizers will benefit agriculture economically. The phosphorus load from Finland is about 4 per cent of that of Lake Ladoga's and point-sources cover only about 10 per cent of that. Therefore, waste water from Finland does not threaten the state of Lake Ladoga.

Investments of about 450 million USD are necessary to reach the targets for water protection within the catchment area of Lake Ladoga. If production could be limited or even some enterprises closed down, these costs could be reduced. To restore the lake's ecological balance to what it was a few decades earlier, more reductions in loads are necessary especially within the agriculture and livestock sector, or significantly more investments should be made in waste water treatment.

If half of the target phosphorus reduction in the water protection action plan is reached, the present eutrophication process could be stopped and the water quality improved at least in some parts of the lake. Water protection measures for acheiving these reductions could be implemented with costs of approximately 150 million USD.

In the long term, water treatment for St. Petersburg should be intensified at least by activated carbon filtration and preferably by ozonation as well. A large raw water reservoir would be the solution for maintianing potable water quality during storms and when the snow melts.

Alternative solutions to improving the potable water quality for St. Petersburg are related to the transfer of cleaner raw water from Lake Ladoga or the upper course of the Vuoksi River. Water quality in Lake Ladoga is not dependent on water protection measures along the Neva and all direct waste water loads could easily be illiminated in the upper Vuoksi. It is possible that waste water effluents do not directly effect the intended intake location in Lake Ladoga either.

The investment costs to bring water quality to the target level will be about 400 million USD if more water is taken from the Neva. If water is transfered from Lake Ladoga the cost will be about 600 million USD and from the Vuoksi 900 mUSD. If a one week raw water reservoir for St. Petersburg is taken from the Neva total investment costs would be close to those for Lake Ladoga.

When additional maintenance costs are taken into account and investments converted to annuity costs, the long term cost effectiveness of Lake Ladoga and Neva River is about the same. Because of the time necessary to construct the water transfer system and possible technical difficulties in construction, the Neva would probably be the most attractive alternative for a period of about 30 years.

Decreasing consumption and leakages would be benefitial. At present per capita water consumption in St. Petersburg is about 540 l/cap/d, which is almost twice as much as in western countries. The more water consumption can be decreased the smaller water treatment and transfer system is needed and the cheaper it is to build and use.

Water for drinking could be delivered separately from water for other purposes. If all inhabitants of St. Petersburg would buy their daily drinking water in bottles (3 l/cap/d), it would cost about 2,700 million USD a year, if the price were equal to Finnish bottle markets. It would be much cheaper for the citizens if the city produced, delivered and sold water. Raw water quality for the production of drinking water should be as good as possible. Natural or artificial groundwater would be the best alternative, but water from the upper Vuoksi or the cleaner parts of Lake Ladoga would be suitable as well.

According to a map examination 15,000 m^3/d (the daily need for drinking and cooking in St. Petersburg) groundwater could easily be taken even from the closest esker, which is located at the shore of Lake Ladoga about 40 km from St. Petersburg. The cost of intake and the transfer system from there to the city border would be about 15 million USD. If water quantity is not sufficient it could be increased by bankfiltration, artificial groundwater or more groundwater transferred from other eskers. The total area of 7 eskers closer than 80 km from St. Petersburg is over 200 km^2. The probable water yield from these eskers would be up to 200,000 m^3/d.

8
RECOMMENDED FUTURE ACTION

8.1
Action Related to Water Pollution Control Measures

8.1.1
Feasibility Study for Water Protection Measures for the Neva River Catchment Area

As a basis for this study the water protection objectives included in the mutual agreement between the Finnish Republic and the Russian Federation must be used. According to this agreement these objectives should be met during 1995. The Finnish has met these guidelines, but Russian still requires huge investments to fulfil the objectives of the agreement. The study can be done as one comprehensive study or it can be done in separate parts divided into the catchment areas of the different principle rivers.

The following issues must be included in the feasibility study:

- evaluation of waste water loads from municipalities exceeding a population of 10,000
- evaluation of waste water loads from major industrial enterprises which have their own treatment plant or which discharge directly to the recipient
- evaluation of the point and non-point pollution loads from agriculture
- cost estimates for different targets to fulfil the set objectives
- priority action programme for investments
- possibilities to finance the investments

From St. Petersburg's perspective it is of great importance to concentrate on the catchment area of Neva River for their water supply. If a comprehensive feasibility study cannot be implemented, at least an areally resticted study should be done. The content of this study is the same as in the larger study.

8.1.2
Feasibility Study for the Main Polluters

The two greatest water polluters of Lake Ladoga with respect to phosphorus loads are the Volkhov aluminium plant and the Svetogorsk pulp and paper mill. Huge reductions in these loads may be achieved with rather small investments. Until these investments can be made feasibility studies are needed.

Environmental investments can be made concurrently with other investments to improve production. One important issue is also the availability of raw materials and transportation costs. The tendency during the Soviet Union was to establish production units far from the areas where raw material was available.

8.2
Actions Related to the Water Supply of St. Petersburg

8.2.1
Pre-Feasibility Study of Alternative Raw Water Sources

To complete this study a more comprehensive investigation is needed. All available data concerning groundwater yields and qualities within the radius of 150 km should be collected. The possibilities to construct water transfer systems either from Lake Ladoga or the upper course of the Vuoksi should be examined, investment and running costs calculated and timetables for implementation drawn. In connection with groundwater use possibilities to produce artificial groundwater should also be studied.

In the future water consumption figures for St. Petersburg should be reduced. In this study the main issue is not to determine the future water consumption, but to study the feasibilities of different alternatives in different water consumption situations.

8.2.2
Pre-Feasibility Study for a Separate Drinking Water Supply

Huge investments and much time are needed before high quality potable water can be distributed in the existing water distribution system of St. Petersburg. The amount of investment can of course be reduced by decreasing water consumption (motivated through tariff policy), by installing water meters and by reducing leakages. Also, the realization of all these measures will take a long time. Quicker and cheaper alternatives for providing safe, potable water and a separate distribution system for smaller quantities can be examined. In this system groundwater should be favoured.

Potential markets and prices should also be examined. On the basis of a market study the system dimensions, the number and location of distribution points and the financial calculations should be done. The implementation of a separate distribution system can be done in phases depending on the markets and the financiers.

8.2.3
Feasibility Study of a Water Supply for St. Petersburg

An overall study of all the investments needed in the field of water supply in St. Petersburg is needed. The pre-feasibility studies mentioned in paragraphs 8.2.1 and 8.2.2 should be used as initial data for this study as well as other existing plans and studies which must be collected and used.

The objective of this study is to prepare a prioritized investment programme for the whole water supply system. Another important objective is to prepare a feasibility financing plan for at least a short-term investment programme.

Institutional questions have an important role in the financing plan as well as in the overall implementation of the programme. That is why these issues must also be included in the study.

The maintenance of the water supply system is an essential activity for the whole water and sewerage works. Other activities include those related to the maintenance of sewerage and waste water treatment. The investment needs of both these main activities should be studied at the same time because the main financiers of the investments are the same, namely water consumers. This kind of comprehensive study should be done undr the supervision of an international financial institution, because the most important result of this study should be an agreed investment programme with realistic prospectives for implementation. Financing for the programme might require international loans.

8.2.4
Pre-feasibility Study of Alternative Water Treatment Technology

The water treatment processes used in Russia as well as in St. Petersburg are conventional. The development of these particular processes has worldwide been rather limited during the last decades. In addition, the authorities in St. Petersburg are rather unaware of technological developments in western countries. This is why they are very interested in the knowledge of this technology and its feasibility in St. Petersburg. The pre-feasibility study could address the following issues:

- presentation of alternative appropriate technologies.
- evaluation of the feasibility of these technologies in St. Petersburg.
- selection of those technologies which are the most feasibile for St. Petersburg.
- presenting the dimensions of alternative and most feasible solutions for water treatment plants in St. Petersburg and preparation of cost estimates for them.
- preliminary cost comparisons of conventional and new technologies.
- conclusions and future recommendations.

As a part of or separate from this study an evaluation of the operation of existing treatment processes should be carried out. As a result of this study the recommendations for the least-costly process and operation modifications will be presented. These modifications should be easily, cheaply and quickly implemented.

9
REFERENCES

1. Ahl, T. & Wiederholm, T. 1977. Svenska vattenkvalitetskriterier. Eutrofierande ämnen. Statens Naturvårdsverk PM 918. 124 pp. (In Swedish.)

2. Chapra, S.C. 1975. Comment on "An Empirical Method of Estimating the Retention of Phosphorus in Lakes" by W.B. Kirchner and P.J. Dillon. - Water Resour. Res., vol. 11, no. 6, pp. 1033-1034.

3. Davydova, N., Kurashov, E., Simola, H., Slepukhina, T. & Subetto, D. 1992. The estimation of the present state of bottom sediments and benthic communitiesin the Sortavala archipelago of Lake Ladoga. In: Viljanen, M. & Drabkova, V. (editors) 1992. Intercalibration of research methods in Lake Ladoga. University of Joensuu, Karelian Institute, Finland. 56 pp. Working papers.

4. Dillon, P.J. & Rigler, F.H. 1974. The phosphorus-chlorophyll relationship in lakes. - Limnol. Oceanogr., vol. 19, no. 5, pp. 767-773.

5. Dillon, P.J. & Rigler, F.H. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. - J. Fish. Res. Board Can., vol. 32, pp. 1519-1531.

6. Edmondsson, W.T. & Lehman, J.T. 1981. The effect of changes in the nutrient income in the state of Lake Washington. - Limnol. Oceanogr. vol. 26, no. 1, pp. 1-29.

7. Filatov. N., Bojarinov, P. & Petrov, M. 1990. Onega-Ladoga-Neva-Bay of Neva - the state of the ecosystem. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

8. Filatov, N. & Heinonen, P. (editors) 1990. Results of the Finnish-Russian joint study of the lakes Onega, Ladoga, and Saimaa conducted in the summer of 1990. The joint study of the Water and Environment Research Institute of the National Board of Waters and Environment, Finland, and the Northern Water Problems Institute of Russian Academy of Sciences was conducted at lake Onega, lake Ladoga, river Neva, and the southern part of lake Saimaa in July-August 1990. Working papers.

9. Finnish National Board of Waters and Environment 1988. Classification of qualitative usefulness of the water systems. Vesi- ja ympäristöhallituksen julkaisuja 20. (In Finnish.)

10. Granberg, K. 1975. Eutrofieringssituationen i Finland. Tionde Nordiska symposiet om vattenforskning. - Nordforsk, publikation vol. 1975, no. 1, pp. 27-33. (In Swedish.)

11. Institute for Lake Research 1993. Present state of lake Ladoga. Working papers, 9 pp. Academy of Science, Russia.

12. Jones, J.R. & Bachmann, R.W. 1976. Prediction of phosphorus and chlorophyll levels in lakes. - J. Water Poll. Control Fed., vol. 48, no. 9, pp. 2176-2182.

13. Kovalenko, V. 1990. Clorophyll-a in epilimnions of lakes. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

14. Kulikova, T. 1990. Zooplankton studies. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

15. Lappalainen, K.M. & Matinvesi, J. 1990. Järven fysikaalis-kemialliset prosessit ja ainetaseet (in Finnish). In: Ilmavirta, V. (editor), Järvien kunnostuksen ja hoidon perusteet, pp. 54-84. Yliopistopaino, Helsinki. ISBN 951-570-051-5.

16. Lappalainen, K.M., Niemi, J. & Kinnunen, K. 1979. A phosphorus retention model and it's application to Lake Päijänne. - Publications of the Water Research Institute, National Board of Waters, Finland, vol. 34, pp. 60-67.

17. Larsen, D.P. & Mercier, H.T. 1976. Phosphorus retention capacity of lakes. - J. Fish. Res. Board. Can., vol. 33, pp. 1742-1750.

18. Lepistö, L. 1990. Phytoplankton studies. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

19. Megard, R.O. 1978. Phytoplankton, photosynthesis, and phosphorus concentration in Lake Minnetonka, Minnesota. - Limnol. Oceanogr., vol. 17, no. 1, pp. 68-87.

20. Niinioja, R., Manninen, M. & Lozovik, P. 1993. The water quality of Lake Ladoga based on results from august 1993 and intercalibration results 1992. Proceedings of the 1st international symposium on the state of Lake Ladoga, November 22-26 1993, St. Petersburg, Russia. Manuscript, 13 pp.

21. OECD 1982. Eutrophication of waters: monitoring, assessment and control. Paris. 154 pp.

22. Pellinen, J. & Soimasuo, R. 1992. Assessment of sediment toxicity on Lake Ladoga. In: Viljanen, M. & Drabkova, V. (editors) 1992. Intercalibration of research methods in Lake Ladoga. University of Joensuu, Karelian Institute, Finland. 56 pp. Working papers.

23. Popov, E.A., Raspopov, I.M., Smirnova, N.P. & Mokijewski, K.A. 1965. Neue Ergebnisse des Komplex-Studiums vom Ladogasee (1956-1962). - Verh. Internat. Verein. Limnol., vol. 16, pp. 97-101.

24. Rahkola, M., Karjalainen, J. & Viljanen, M. 1992. Zooplankton of the northern Lake Ladoga. In: Viljanen, M. & Drabkova, V. (editors) 1992. Intercalibration

of research methods in Lake Ladoga. University of Joensuu, Karelian Institute, Finland. 56 pp. Working papers.

25. Reckhow, K.H. 1977. Phosphorus models for lake management. Ph. D. dissertation, Harvard University. 302 pp.

26. Rumjantsev, V.A. & Rodionov, V.Z. (editors) 1991. Asiantuntijakomitean raportti itäisen Suomenlahden ja Nevanlahden ekokogisesta tilasta. Etukäteispainos. Neuvostoliiton tiedeakatemian Leningradin tiedekeskuksen puhemiehistö. Neuvostoliiton tiedeakatemian järvi-instituutti. (In Finnish.)

27. Russian Research Institute for Agricultural Microbiology 1993. Geography, climate, geology, population and industry of the Leningrad region. Working papers. 7 pp.

28. Sabylina, A. 1990. Nitrogen ang phosphorus situation in Lake Ladoga. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

29. Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. - Arch. Hydrobiol., vol. 62, no. 1, pp. 128.

30. Sandman, O. & Kalmikov, M. 1990. Sediments of the lakes Onega and Ladoga. In: Filatov, N. & Heinonen, P. (editors) 1990. Working papers.

31. Schindler, D.W., Fee, E.J. & Ruszczynski, R. 1978. Phosphorus inputs and its concequences for phytoplankton standing crop and production in experimental lakes area and similar lakes. - J. Fish. Res. Board. Can., vol. 35, no. 2, pp. 190-196.

32. Särkkä, J. & Kurashov, E. 1992. Meiofauna in the profundal zone of the northern part of Lake Ladoga. In: Viljanen, M. & Drabkova, V. (editors) 1992. Intercalibration of research methods in Lake Ladoga. University of Joensuu, Karelian Institute, Finland. 56 pp. Working papers.

33. Viljanen, M. & Drabkova, V. (editors) 1992. Intercalibration of research methods in Lake Ladoga. University of Joensuu, Karelian Institute, Finland. 56 pp. As a part of the joint Russian-Finnish research works on the evaluation of the human impact on Lake Ladoga, Lake Saimaa, Lake Onega, River Neva and the eastern Gulf of Finland water system, the joint expedition was arranged to Lake Ladoga in October 1-3, 1991. Working papers.

34. Vodokanal St. Petersburg 1994. Comments on the draft version of this report by Vice President Maharandin V.N.

35. Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing water, with particular reference to nitrogen and phosphorus as factors in eutrophication. Tech. Rep. OECD Paris DAS/CSI/68.27. 159 pp.

36. Vollenweider, R.A. 1976. Advanced in defining critical phosphorus loading levels for phosphorus in lake eutrophication. - Mem. Ist. Ital. Idrobiol., vol. 33, pp. 53-83.

37. Vollenweider, R.A. & Kerekes, J.J. 1980. Background and summary results of the OECD cooperarive program on eutrophication. Proceedings of International Symposion on Inland Waters and Lake Restoration, held at Portland, Maine USA, september 8-12, 1980. U.S. Environmental Protection Agency, Washington DC.

38. Walker, W.W. Jr. 1977. Some analytical methods applied to lake water quality problems. Ph. D. dissertation, Harvard University.

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APPENDIXES

1. Comparison of standards for drinking water in Russia and in the European Union
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Appendix 1

Comparison of standards for drinking water in Russia and in the European Union

Substance	Norm in Russia	EU, Guide level	EU, Maximum Admissible Concentration
Colour	< 20 (own scale)	< 1 (mg/l Pt scale)	20 (mg/l Pt scale)
Turbidity, SiO_2 mg/l	< 1.5	< 1	< 10
Maximum temperature, °C		12	25
pH	6.0 - 9.0	6.5 - 8.5	9.5
Chlorides, Cl^- mg/l	< 350	< 25	
Sulphates, SO_4 mg/l	< 500	< 25	250
Calcium, Ca mg/l		< 100	
Aluminium, mg/l	< 0.5	< 0.05	0.2
Total hardness, mmol Ca/l	< 7.0	> 1.5	
Dry residues, mg/l	< 1 000		1 500 (180 °C)
Nitrates, NO_3 mg/l	< 45	< 25	50
Ammonium, NH_4 mg/l		< 0.05	0.5
COD_{Mn}, O_2 mg/l		< 2	5
Iron, Fe mg/l	< 0.3	< 0.05	0.2
Manganese, Mn mg/l	< 0.1	< 0.02	0.05
Copper, Cu mg/l	< 1.0	< 0.1 (at treatment plants or pumping stations) < 3 (available for customers)	
Zinc, Zn mg/l	< 5.0	< 0.1 (at treatment plants or pumping stations) < 5 (available for customers)	
Phosphorus, PO_4 mg/l	< 3.5	< 0.6	7.5
Free Chlorine, Cl_2 mg/l	0.3 - 0.5		
Total Chlorine, Cl_2 mg/l	0.8 - 1.2		should not constitute a public helth hazard
Total coliforms, pcs/ ml	< 100		0 (95 % of samples)
Faecal coliforms, pcs/ l	< 3		0

Appendix 2

References for the estimation of phosphorus loads to Lake Ladoga (appendixes 3 and 4 are based on them)

1. **Russian-Finnish Joint Comississsion of Environmental Protection. Working group of protection of water systems and sea environment against pollution.** 1993. Report of Russian party conserning "Action programme for reducement of water pollution and realization of measures of water protection in the basin of Baltic Sea and in other areas near border between Federation of Russia and Republic of Finland".

2. **Russian Academy of Sciencies, Institute of Limnology.** 1993. Material collected especially for report "Prefeasibility study of the protection measures in the river Neva catchment area to ensure the water supply of St. Petersburg.

3. **Kymi Water and Environment District.** 1993.

4. **Plancenter LTD.** 1991. Environmental priority action programme for Leningrad, Leningrad Region, Karelia and Estonia. Prefeasibility study No 8. Reduction of the environmental effects of Svetogorsk pulp and paper mill.

5. **Plancenter LTD.** 1991. Environmental priority action programme for Leningrad, Leningrad Region, Karelia and Estonia. Prefeasibility study No 7. Reduction of the environmental effects of Syasstroy pulp and paper mill and Volkhov aluminium factory.

6. **Plancenter LTD.** 1991. Environmental priority action programme for Leningrad, Leningrad Region, Karelia and Estonia. Prefeasibility study No 12. Reduction of the environmental effects of Pitkyaranta pulp and paper mill.

7. **Plancenter LTD.** 1991. Environmental priority action programme for Leningrad, Leningrad Region, Karelia and Estonia. Prefeasibility study No 6. Development of livestock farming waste management in the Leningrad Region.

8. **Plancenter LTD.** 1991. Environmental priority action programme for Leningrad, Leningrad Region, Karelia and Estonia. Synthesis report.

9. Analysis made by the complex in 1993

Appendix 3

Phosphorus discharges in the basin of Lake Ladoga

Lake*/River* By map study
ms Municipal sewer
Onega + ms One part directly to Lake Onega, one part to the municipal sewer

▨ Estimate
For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Point of discharge	Waste water treatment	Number of inhabitants or capacity/a			Phosphorus load							References	
				Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	Offic. of ref.	No of ref.
Nearest drainage area of Lake Ladoga															
Priozersk	Municipality	Ladoga*			19 600							14	14		
Lahdenpohja	Municipality	Ladoga	Filtration		12 000				1.5			1.5	1.5	Yes	8
Sortavala	Municipality	Ladoga*			22 800							17	17		
Pitkyaranta	Municipality	Ladoga*			14 800							11	11		
Pitkyaranta	Quarry combine	Direct+ms		Stone material										No	2
Pitkyaranta	Pulp and paper mill		Primary +	Unbleached pulp	82 000	t					14	14	27	No	3
			Secondary	Tall oil	6 100	t					27			No	3
				Urpentine	1 000	t			25					Yes	6
Sinyavino	Prod.comb. Sinjavinskoya	Naziya	Biological	Poultry			3.0		2.8	3.8		2.6	3.8	Yes	1
					2 540 000	Heads			2.6					Yes	7
Putilovo	Sovkhoz Dalnaya Poljana			Cattle	1 200	Heads						0.53	0.53	No	2
Romanovka	Sovkhoz Sputnik	Morye	2 stage	Pigs			0.07		0.01	0.01		0.01	17	Yes	1
			biolog. pond		108 000	Heads			17					Yes	7
											5 (1993)			No	9
Melnikovo	Sovkhoz Melnikovo			Cattle	1 200	Heads						0.53	0.53	No	2
Laskela	Paper mill	Janisjoki*	No treatment	Paper + pulp	300 + 12 640	t								Yes	1
Olonez	Municipality	Olonka*			12 200							8.9	8.9		
Total point source load												70	100		
Non point source load															
	Fertilization losses during transport and storage									411		411	411	No	2
	Runoff from fields									120		120	120	No	2
	Runoff from meadows and pastures									98		98	98	No	2
	Municipal waste water without treatment									222		222	222	No	2
Total non point source load										851		851	851		
Natural load												415	415		
Total direct discharges to lake Ladoga												1 336	1 366		

Appendix 3

Phosphorus discharges in the basin of Lake Ladoga

Lake*/River* By map study
ms Municipal sewer
Onega + ms One part directly to Lake Onega, one part to the municipal sewer

▨ Estimate
For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Point of discharge	Waste water treatment	Number of inhabitants or capacity/a			Phosphorus load							References	
				Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	Offic. of ref.	No of ref.
Drainage area of river Volkhov															
Novaya Ladoga	Municipality	Volkhov*			12 300							9.0	9.0		
Volkhov	Municipality	Volkhov*	Biologic.		50 600		19		23	26		19	26	Yes	1
Volkhov	Aluminium plant	Volkhov	Settling ponds	Aluminium	20 000	t	19		295	470		19	470	Yes	1
				Superphosphate	150 000	t			294					No	2
				Acid(sulf., phosph.),					280					Yes	5
				Cryolite etc.					359					Yes	8
Kirishi	Municipality	Volkhov*			51 900							38	38		
Kirishi	Biochmical factory	Volkhov							2			2.2	2.2	No	2
Kirishi	Oil refinery	Tshernaya					24		24	23		0.80	24	Yes	1
									1					No	2
Tshudovo	Municipality	Volkhov*	Biologic.		17 600					12		12	12	Yes	1
Novgorod	Municipality	Volkhov*	Mech. + Biologic.		232 700				106	602		106	602	Yes	1
Novgorod	Fibreglass factory	ms		Fibreglass products	4 300	t								No	2
Novgorod	Fish factory	ms												No	2
Novgorod	Meat processing factory	ms			17 000	t			47			47	47	No	2
Novgorod	Milk processing factory	ms		Milk + butter	38 000 + 336	t			11			11	11	No	2
Novgorod	Bakery	ms			8 000	t			0.40			0.40	0.40	No	2
Novgorod	Prod. comb. Azot			Fertiliz. + chem.	5 537 500	t		28	30	12		12	30	Yes	1
Kiselnya	Sovkhoz Tchaplinski	Elena*		Cattle	1 200	Heads						0.53	0.53	No	2
Ljuban	Sovkhoz Ljuban	Tigoda*		Cattle	800	Heads						0.35	0.35	No	2
Malaja Vishera	Municipality	Vishera*			15 300							11	11		
Total point source load												288	1 284		
Non point source load (Includes phosphorus load from Lake Ilmeni)												2 327	1 331		
Natural load												115	115		
Total direct discharges via river Volkhov								2 220	2 400	3 570	2 730	2 730	2 730	No	2

Appendix 3

Phosphorus discharges in the basin of Lake Ladoga

Lake*/River*	By map study
ms	Municipal sewer
Onega + ms	One part directly to Lake Onega, one part to the municipal sewer
▨	Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Point of discharge	Waste water treatment	Number of inhabitants or capacity/a			Phosphorus load							References	
				Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	Offic. of ref.	No of ref.
Drainage area of river Svir															
Lodeinoye pole	Municipality	Svir*			26 400							19	19		
Lodeynoye pole	Wood processing factory													Yes	1
Podporozhje	Municipality	Svir*			23 700							17	17		
	Sovkhoz Podporozhski	Svir*		Cattle	1 200	Heads						0.53	0.53	No	2
Total point source load												37	37		
Non point source load (Includes phosphorus load from Lake Onega)												1 383	1 383		
Natural load												90	90		
Total discharges via river Svir								1 460	1 320	1 750	1 510	1 510	1 510	No	2
Drainage area of river Vuoksa															
Kamennogorsk	Municipality				4 900							3.6	3.6		
Kamennogorsk	Paper mill								0.06	0.12		0.06	0.12	Yes	1
Kamennogorsk	Quarry													Yes	9
Lesogorsk	Municipality				6 800							5.0	5.0		
Lesogorsk	Syntethic fibre factory						0.12		0.72	0.47		0.12	0.72	Yes	1
Svetogorsk	Municipality	Vuoksa*			16 200				15	15		15	15		3
Svetogorsk	Pulp and paper mill		Mech. +	Bleached hardwood pulp	150 000	t	36		105	83		36	210	Yes	1
			Biologic. +	Unbleached softwood kraft pulp	135 000	t			41					No	2
			Flotation +	Bleached viscosesodiun pulp	130 000	t					210			No	3
			Filtration	Paper and other products					80					Yes	4
	Sovkhoz Udarnik		Biological	Poultry	660 000	Heads			2.9			2.9	2.9	Yes	7
Total load from Finland												250	250	No	3
Total point source load												313	487		
Non point source load												470	296		
Natural load												127	127		
Total discharges via river Vuoksa								920	750	1 060	910	910	910	No	2

Appendix 3

Phosphorus discharges in the basin of Lake Ladoga

Lake*/River*	By map study
ms	Municipal sewer
Onega + ms	One part directly to Lake Onega, one part to the municipal sewer

▨ Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Point of discharge	Waste water treatment	Number of inhabitants or capacity/a			Phosphorus load							References	
				Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	Offic. of ref.	No of ref.
Drainage areas of rivers Syas, Pasha and Oyat															
Syasstroy	Municipality	Syas*			18 000		Included in phosphorus load of industry								8
Syasstroy	Pulp and paper mill	Ladoga	Mech. + Biologic.	Pulp (sulph. + mech.)	0 000 + 60 000	t	76		40	21		21	90	Yes	1
				Board + paper	0 000 + 79 000	t			39					No	2
				Tissue	58 000	t				36				No	3
				Byproducts					90					Yes	5
Aleksino	Sovkhoz Leninski put	Syas*		Cattle	1 200	Heads						0.53	0.53	No	2
Tihvin	Municipality	Tihvin*			70 400				29	30		29	30		1
Boksitogorsk	Municipality	Syas*			23 800							17	17		
Boksitogorsk	Glinozem	Pryadomlya	Mech. + Biologic.				3.1		6.5	0.5		0.5	6.6	Yes	1
									6.6					No	2
Pikalyovo	Municipality	Ryadan*			26 500							19	19		
Pikalyovo	Glinozem	Ryazano												No	2
Bor	Sovkhoz Boksitogorski	Syas*		Cattle	1 200	Heads						0.53	0.53	No	2
Pasha, Potanino	Sovkhoz Pashsky	Voronezhki	Mech. + Biological	Cattle	20 130	Heads						8.9	8.9	Yes	1
														Yes	7
Total point source load												97	173		
Non point source load												577	601		
Natural load												176	176		
Total discharges via other rivers								1 090	620	1 140	950	950	950	No	2

Total disharges in the basin of Lake Ladoga	7 436	7 466	

Appendix 4

▨ Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Development scenarios for Lake Ladoga

Town or location of the enterprice or livestock farm	Type of activity	Number of inhabitants or capacity/a			Phosphorus load							Phosphorus load in different scenarios		
		Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	O-solution t/a	Intermediate t/a	Agreement t/a
Nearest drainage area of Lake Ladoga														
Priozersk	Municipality		19 600							14	14	14		1.4
Lahdenpohja	Municipality		12 000				1.5			1.5	1.5	1.5		0.88
Sortavala	Municipality		22 800							17	17	17		1.7
Pitkyaranta	Municipality		14 800							11	11	11		1.1
Pitkyaranta	Quarry combine	Stone material												
Pitkyaranta	Pulp and paper mill	Unbleached pulp	82 000	t					14	14	27	27		14
		Tall oil	6 100	t					27					
		Urpentine	1 000	t			25							
Sinyavino	Prod.comb. Sinjavinskoya	Poultry			3.0		2.8	3.8		2.6	3.8	3.2		1.6
			2 540 000	Heads			2.6							
Putilovo	Sovkhoz Dalnaya Poljana	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Romanovka	Sovkhoz Sputnik	Pigs			0.07		0.01	0.01		0.01	17	5.0		2.5
			108 000	Heads			17							
									5 (1993)					
Melnikovo	Sovkhoz Melnikovo	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Laskela	Paper mill	Paper + pulp	19 300 + 12 640	t										
Olonez	Municipality		12 200							8.9	8.9	8.9		0.89
Total point source load										70	100	88		24
Non point source load														
	Fertilization losses during transport and storage							411		411	411	411		206
	Runoff from fields							120		120	120	120		60
	Runoff from meadows and pastures							98		98	98	98		49
	Municipal waste water without treatment							222		222	222	222		111
Total non point source load								851		851	851	851		426
Natural load										415	415	415		415
Total direct discharges to lake Ladoga										1 336	1 366	1354	1109	865

Appendix 4

Development scenarios for Lake Ladoga

▨ Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Number of inhabitants or capacity/a			Phosphorus load							Phosphorus load in different scenarios		
		Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	0-solution t/a	Intermediate t/a	Agreement t/a
Drainage area of river Volkhov														
Novaya Ladoga	Municipality		12 300							9.0	9.0	9.0		0.90
Volkhov	Municipality		50 600		19		23	26		19	26	23		3.7
Volkhov	Aluminium plant	Aluminium	20 000	t	19		295	470		19	470	307		154
		Superphosphate	150 000	t			294							
		Acid(sulf., phosph.),					280							
		Cryolite etc.					359							
Kirishi	Municipality		51 900							38	38	38		3.8
Kirishi	Biochmical factory						2			2.2	2.2	2.2		1.1
Kirishi	Oil refinery				24		24	23		0.80	24	24		12
							1							
Tshudovo	Municipality		17 600					12		12	12	12		1.3
Novgorod	Municipality		232 700				106	602		106	602	106		17
Novgorod	Fibreglass factory	Fibreglass products	4 300	t										
Novgorod	Fish factory													
Novgorod	Meat processing factory		17 000	t			47			47	47	47		24
Novgorod	Milk processing factory	Milk + butter	38 000+336	t			11			11	11	11		5.5
Novgorod	Bakery		8 000	t			0.40			0.40	0.40	0.40		0.20
Novgorod	Prod. comb. Azot	Fertiliz. + chem.	5 537 500	t		28	30	12		12	30	21		10
Kiselnya	Sovkhoz Tchaplinski	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Ljuban	Sovkhoz Ljuban	Cattle	800	Heads						0.35	0.35	0.35		0.18
Malaja Vishera	Municipality		15 300							11	11	11		1.1
Total point source load										288	1 284	612		234
Non point source load (Includes phosphorus load from Lake Ilmeni)										2 327	1 331	1829		915
Natural load										115	115	115		115
Total direct discharges via river Volkhov						2 220	2 400	3 570	2 730	2 730	[illegible]	2556	1910	1264

Appendix 4

Development scenarios for Lake Ladoga

▨ Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

Town or location of the enterprice or livestock farm	Type of activity	Number of inhabitants or capacity/a			Phosphorus load							Phosphorus load in different scenarios		
		Produots	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	0-solution t/a	Intermediate t/a	Agreement t/a
Drainage area of river Svir														
Lodeinoye pole	Municipality		26 400							19	19	19		1.9
Lodeynoye pole	Wood processing factory													
Podporozhje	Municipality		23 700							17	17	17		1.7
	Sovkhoz Podporozhski	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Total point source load										37	37	37		3.9
Non point source load (includes phosphorus load from Lake Onega)										1 383	1 383	1383		691
Natural load										90	90	90		90
Total discharges via river Svir						1 460	1 320	1 750	1 510	1 510	1 510	1510	1148	785
Drainage area of river Vuoksa														
Kamennogorsk	Municipality		4 900							3.6	3.6	3.6		0.36
Kamennogorsk	Paper mill						0.06	0.12		0.06	0.12	0.09		0.05
Kamennogorsk	Quarry													
Lesogorsk	Municipality		6 800							5.0	5.0	5.0		0.50
Lesogorsk	Syntethic fibre factory				0.12		0.72	0.47		0.12	0.72	0.42		0.21
Svetogorsk	Municipality		16 200				15	15		15	15	15		1.2
Svetogorsk	Pulp and paper mill	Bleached hardwood pul	150 000	t	36		105	83		36	210	210		9.0
		Unbleached softwood k	135 000	t			41							
		Bleached viscosesodiun	130 000	t					210					
		Paper and other products					80							
	Sovkhoz Udarnik	Poultry	660 000	Heads			2.9			2.9	2.9	2.9		1.5
Total load from Finland										250	250	250		250
Total point source load										313	487	487		263
Non point source load										470	296	383		191
Natural load										127	127	127		127
Total discharges via river Vuoksa						920	750	1 060	910	910	910	997	789	581

Appendix 4

▨ Estimate

For municipalities 0.73 kg/inhabitant/a
For cattle 0.44 kg/head/a
For natural load 9 kg/km²/a

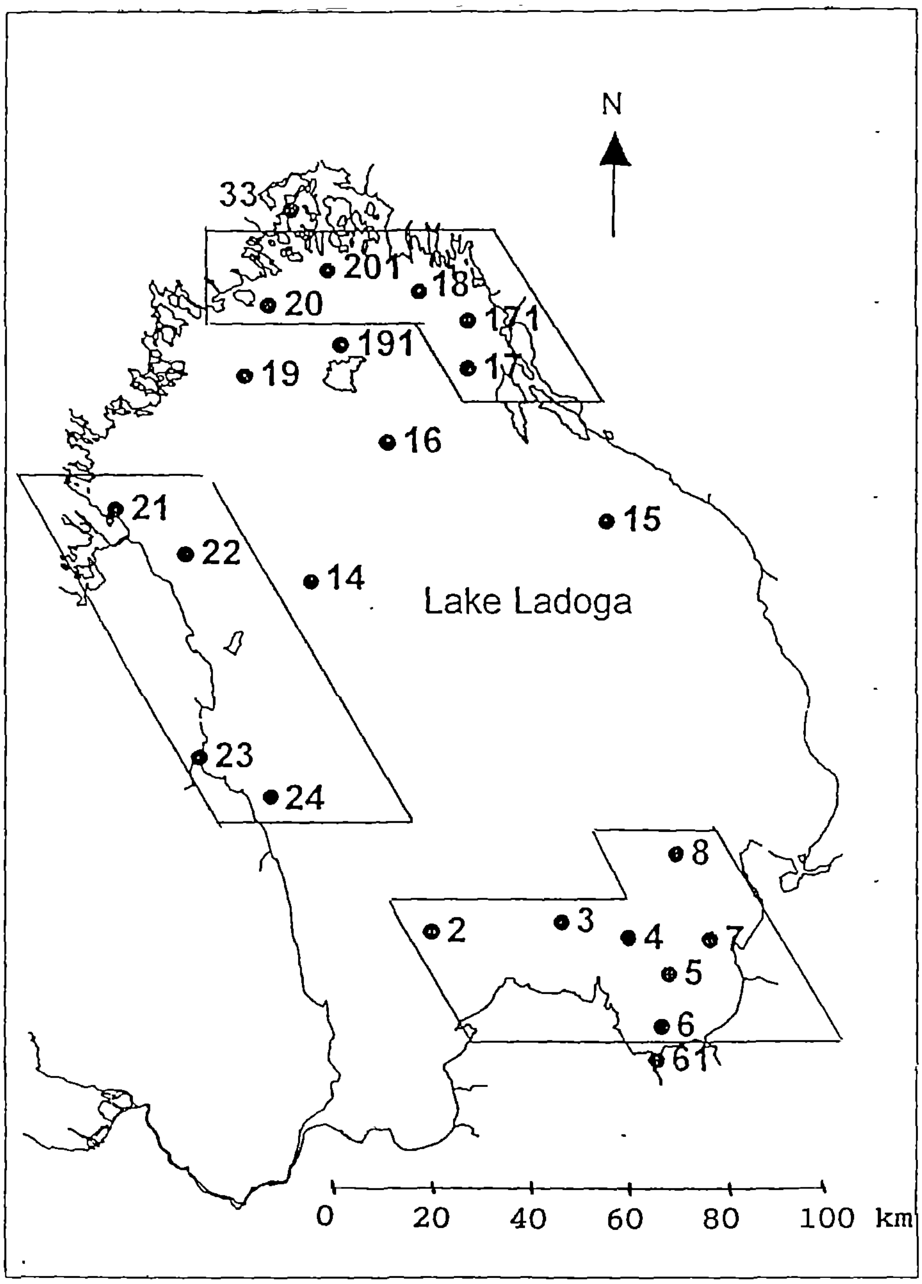
Development scenarios for Lake Ladoga

Town or location of the enterprice or livestock farm	Type of activity	Number of inhabitants or capacity/a			Phosphorus load							Phosphorus load in different scenarios		
		Products	Inhabitants Capacity/a	Unit	1987 t/a	1989 t/a	1990 t/a	1991 t/a	1992 t/a	Min t/a	Max t/a	0-solution t/a	Intermediate t/a	Agreement t/a
Drainage areas of rivers Syas, Pasha and Oyat														
Syasstroy	Municipality		18 000		Included in phosphorus load of industry									
Syasstroy	*Pulp and paper mill*	Pulp (sulph. + mech.)	120 000 + 60 000	t	76		40	21		21	90	36		7.2
		Board + paper	50 000 + 79 000	t			39							
		Tissue	58 000	t				38						
		Byproducts					90							
Aleksino	Sovkhoz Leninski put	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Tihvin	Municipality		70 400				29	30		29	30	29		5.1
Boksitogorsk	Municipality		23 800							17	17	17		1.7
Boksitogorsk	Glinozem				3.1		6.5	0.5		0.5	6.6	3.6		1.8
							6.6							
Pikalyovo	Municipality		26 500							19	19	19		1.9
Pikalyovo	Glinozem													
Bor	Sovkhoz Boksitogorski	Cattle	1 200	Heads						0.53	0.53	0.53		0.26
Pasha, Potanino	Sovkhoz Pashsky	Cattle	20 130	Heads						8.9	8.9	8.9		4.4
Total point source load										97	173	116		23
Non point source load										677	601	639		319
Natural load										176	176	176		176
Total discharges via other rivers						1 090	620	1 140	950	950	950	931	724	518
Total disharges in the basin of Lake Ladoga										7 436	7 466	7348	5680	4013

Appendix 5. 1(2) Water quality in Lake Ladoga, August 1993. Intermediate depth is mostly located halfway between the surface and the bottom.

	Whole lake (Location of 22 sampling stations is shown in next page)						Sampling station 2, SW part of the lake		
	Depth 1 m		Intermediate depth		Near bottom		Depth 1 m	Intermediate depth	Near bottom
	Mean	Range	Mean	Range	Mean	Range			
Colour	36	25-70	35	25-70	34	25-70	30	30	25
Turbidity, FTU	1.2	0.29-5.1	1.0	0.21-3.6	1.1	0.24-5.2	0.87	0.97	0.90
pH	7.8	7.6-8.1	7.6	7.2-7.9	7.4	6.6-7.7	7.9	7.8	7.3
Conductivity, mS/m	10.2	8.0-14.9	10.3	9.0-15.0	10.1	9.3-12.1	10.5	10.4	9.8
COD(Mn), mg O_2/l	8.8	7.5-16	8.4	7.1-18	7.7	6.9-10	7.5	7.2	7.1
Oxygen, mg/l	9.7	8.2-11.2	10.4	7.2-13.0	10.6	0.3-13.5	9.6	9.6	10.8
Oxygen, %	99	85-107	95	75-102	88	3-103	99	99	90
Total phosphorus, µg/l	24	12-71	22	12-73	27	12-170	12	13	13
Total nitrogen, µg/l	670	580-850	650	540-820	690	580-1200	590	580	700
Iron, µg/l	110	40-470	110	37-510	140	34-890	47	39	73
Manganese, µg/l	14	<5-74	13	<5-76	43	<5-610	7	8	11
Aluminium, µg/l	41	13-150	45	14-170	48	17-130	22	20	36
Cadmium, µg/l	<0.1	<0.1	<0.1	<0.1-0.7	<0.1	<0.1-0.1	<0.1	0.7	<0.1
Copper, µg/l	<1	<1-1.7	<1	<1-1.7	<1	<1-1.3	<1	<1	<1
Zinc, µg/l	2	1-3	2	<1-5	2	<1-4	2	2	2
Nickel, µg/l	<1	<1-1	<1	<1-1	<1	<1-1	<1	<1	<1
Cobalt, µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1

Appendix 5. 2(2) Sampling stations in August 1993 (Niinioja et al 1993).



Appendix 6. 1 (6) Water quality in Neva River, years 1991-1993.
The figures represent the mean quality and maximum values of raw water of four drinking water plants utilizing Neva's water.

	Year 1993, january-august		Year 1992		Year 1991	
	Mean	Max.	Mean	Max.	Mean	Max
Colour	28	32	29	36	27	41
pH	7.5	8.8	7.4	9.0	7.4	8.7
Alkalinity, meqv/l	0.45	0.54	0.47	0.65	0.48	0.60
COD(Mn), mg O_2/l	7.6	9.8	7.3	10.5	7.7	11.5
COD(Cr), mg O_2/l	23	27	22	32	20	32
Oxygen, mg/l	12.3	14.4	11.7	13.8	11.1	13.6
Total phosphorus, µg/l					27	
Ammonia, mg/l	0.19	0.98	0.20	0.71	0.28	1.7
Nitrate, mg/l	1.9	3.1	1.9	2.5	1.4	2.2
Nitrite, mg/l	0.017	0.033	0.02	0.066	0.019	0.035
Chloride, mg/l	7.1	8.7	7.3	10.2	8.1	14.2
Sulphate, mg/l	10.4	17.3	13.0	26	11.8	27
Hardness, meqv/l	1.0	5.6	0.77	1.3	0.73	1.0
Oils, mg/l	0.05	0.05	0.05	0.05	0.07	0.5
Faecal coliform bacteria, 1/ml	109	700	87	700		
Iron, mg/l	0.07	0.10	0.10	0.41	0.11	0.41
Aluminium, mg/l	0.02	0.08	0.04	0.32	0.02	0.09
Copper, µg/l	3	6	3	7	4	12
Nickel, µg/l	4	28	6	25	7	26
Zinc, µg/l	11	43	12	27	9	29
Cadmium, µg/l	1	1	1	1	6	10
Chromium, µg/l	10	10	10	10	10	10
Lead, µg/l	1	14				
Cobalt, µg/l	30	80	30	110	20	80

Appendix 6. 2(6) Water quality in Neva River, year 1991. The figures represent the quality of raw water of four drinking water plants utilizing Neva's water.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	28	34	25	33	28	34	28	41
pH	7.3	7.8	7.35	8.0	7.5	8.0	7.4	8.5
Alkalinity, meqv/l	0.49	0.53	0.47	0.51	0.48	0.53	0.46	0.51
COD(Mn), mg O_2/l	7.5	9.9	7.8	9.9	7.0	9.8	8.0	10.4
COD(Cr), mg O_2/l	19.5	26.5	20.2	24.5	19.7	24.5	20.5	31.5
Oxygen, mg/l	11.1	13.6	11.3	13.6	10.9	13.1	11.1	13.4
Ammonia, mg/l	0.24	0.53	0.22	0.33	0.21	0.39	0.21	0.44
Nitrate, mg/l	1.50	2.21	1.45	1.98	1.44	1.98	1.35	2.12
Nitrite, mg/l	0.018	0.032	0.016	0.028	0.021	0.035	0.019	0.033
Chloride, mg/l	8.9	14.2	7.7	8.1	8.1	8.8	7.7	9.0
Sulphate, mg/l	11.3	17.1	10.6	14.3	12.1	16.9	12.3	27.1
Hardness, meqv/l	0.75	0.82	0.67	0.77	0.72	0.78	0.76	1.0
Oils, mg/l	0.07	0.3	0.06	0.11	0.09	0.34	0.05	0.10
Faecal coliform bacteria, 1/ml								
Iron, mg/l	0.09	0.18	0.09	0.18	0.13	0.34	0.10	0.26
Aluminium, mg/l	0.01	0.02	0.02	0.04	0.02	0.09	0.02	0.07
Copper, µg/l	3	4	5	7	5	12	4	7
Nickel, µg/l	6	16	12	26	5	13	4	11
Zinc, µg/l	7	17	3	10	13	29	13	21
Cadmium, µg/l	6	10	8	10	6	10	6	10
Chromium, µg/l	10	10	10	10	10	10	10	10
Lead, µg/l			10					
Cobalt, µg/l	20	70	10	40	10	30	20	40

Appendix 6. 3(6) Water quality in Neva River, year 1992. The figures represent the quality of raw water of four drinking water plants utilizing Neva's water.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	29	34	28	30	29	32	29	33
pH	7.3	7.6	7.4	8.0	7.3	7.6	7.3	7.5
Alkalinity, meqv/l	0.48	0.52	0.46	0.51	0.47	0.52	0.47	0.51
COD(Mn), mg O_2/l	7.2	7.7	7.0	8.1	7.5	10.5	7.4	8.9
COD(Cr), mg O_2/l	21.4	25.0	22.5	28.1	21.9	27.4	23.6	32.2
Oxygen, mg/l	11.8	13.8	11.6	13.5	11.5	13.3	11.7	13.6
Ammonia, mg/l	0.16	0.25	0.18	0.26	0.18	0.31	0.19	0.27
Nitrate, mg/l	1.88	2.43	1.82	2.07	1.86	2.52	1.88	2.25
Nitrite, mg/l	0.017	0.033	0.016	0.034	0.022	0.066	0.022	0.046
Chloride, mg/l	7.6	10.2	7.1	8.2	7.2	8.3	7.2	8.4
Sulphate, mg/l	13.7	26.3	12.5	20.5	12.5	22.4	13.3	21.6
Hardness, meqv/l	0.75	1.2	0.75	1.0	0.77	0.95	0.82	1.3
Oils, mg/l	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Faecal coliform bacteria, 1/ml	12	70	1	6	210	700	24	240
Iron, mg/l	0.08	0.12	0.10	0.20	0.11	0.16	0.12	0.41
Aluminium, mg/l	0.02	0.05	0.04	0.15	0.03	0.08	0.06	0.32
Copper, µg/l	3	7	3	5	3	5	4	7
Nickel, µg/l	5	11	5	13	6	25	6	16
Zinc, µg/l	8	16	11	25	12	19	11	27
Cadmium, µg/l	1	1	1	1	1	1	1	1
Chromium, µg/l	10	10	10	10	10	10	10	10
Lead, µg/l								
Cobalt, µg/l	20	30	30	80	20	60	40	110

Appendix 6. 4(6) Water quality in Neva River, January-August 1993. The figures represent the quality of raw water of four drinking water plants utilizing Neva's water.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	28	32	28	32	27	31	28	32
pH	7.4	8.0	7.6	8.7	7.5	8.7	7.6	8.8
Alkalinity, meqv/l	0.46	0.54	0.44	0.46	0.43	0.48	0.45	0.50
COD(Mn), mg O_2/l	7.8	8.8	7.8	9.2	7.6	9.8	7.7	9.6
COD(Cr), mg O_2/l	22.8	25.5	22.9	26.6	23.9	26.5	22.4	27.3
Oxygen, mg/l	12.2	14.3	12.1	14.0	11.7	13.8	12.2	13.8
Ammonia, mg/l	0.18	0.32	0.13	0.22	0.12	0.18	0.13	0.25
Nitrate, mg/l	1.93	3.08	1.81	2.65	1.74	2.59	1.88	2.94
Nitrite, mg/l	0.017	0.026	0.014	0.016	0.019	0.033	0.016	0.024
Chloride, mg/l	7.7	8.8	6.8	7.5	6.5	8.6	7.1	8.2
Sulphate, mg/l	10.7	17.3	10.3	15.1	10.0	16.5	10.0	13.8
Hardness, meqv/l	0.94	1.1	1.5	5.6	0.87	0.95	0.93	1.1
Oils, mg/l	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Faecal coliform bacteria, 1/ml	15	70	3	6	370	700	3	6
Iron, mg/l	0.06	0.09	0.06	0.10	0.07	0.09	0.06	0.08
Aluminium, mg/l	0.02	0.02	0.02	0.04	0.02	0.03	0.02	0.04
Copper, µg/l	4	6	3	6	3	6	3	6
Nickel, µg/l	6	28	3	8	3	5	3	5
Zinc, µg/l	7	12	10	17	22	43	7	9
Cadmium, µg/l	1	1	1	1	1	1	1	1
Chromium, µg/l	10	10	10	10	10	10	10	10
Lead, µg/l			1	6			2	14
Cobalt, µg/l	30	60	30	80	30	70	30	70

Appendix 6. 5(6) Water quality in Neva River, September 1993. The figures represent the quality of raw water of two drinking water plants utilizing Neva's water.

	Southern drinking water plant	Main drinking water plant
Oxygen, mg/l	10.9	10.7
Turbidity, FTU	2.4	2.4
Suspended solids, mg/l	4.2	3.8
Conductivity, mS/m	10.4	10.2
Alkalinity, meqv/l	0.52	0.51
pH	7.6	7.7
Colour	35	35
COD(Mn), mg O_2/l	8.2	8.0
COD(Cr), mg O_2/l	26	27
Total nitrogen, µg/l	660	660
Nitrate, µg NO_3-N/l	270	250
Nitrite, µg NO_2-N/l	2.0	2.0
Ammonia, µg NH_4-N/l	13	25
Total phosphorus, µg/l	27	26
Phosphate, µg/l	<1	1
Chloride, mg/l	7.2	7.0
Total iron, µg/l	150	170
Iron, filtered sample, µg/l	39	47
Sulphate, mg/l	13	14
Faecal coliform bacteria (44 °C), 1/100 ml	930	10000
Coliform bacteria (35 °C), 1/100 ml	1500	11000
Total hardness, meqv/l	0.05	0.04
Zinc, µg/l	1.5	18
Selenium, µg/l	0.49	1.2
Nickel, µg/l	0.98	1.2
Lead, µg/l	0.18	0.17
Copper, µg/l	0.82	0.82
Chromium, µg/l	0.82	0.82
Cadmium, µg/l	0.014	<0.005
Aluminium, µg/l	50	72
Arsene, µg/l	0.36	0.35
Barium, µg/l	15	14
Boron, µg/l	12	-11
Manganese, µg/l	6.5	9.2

Appendix 6. 6(6) Reported water quality of the Neva in 1985 and 1990.

Parametre	Unit	Gost norm	1985 mean	1985 max	1990 mean	1990 max
Turbidity	mg/l	20	3.78	15.2	11.1	134.9
Colour	degrees	35	33	43	32	59
pH		6.5-8.5	7.1	8.3	7.5	8.3
Iron	mg/l	1.0	0.11	0.26	0.21	0.41
COD$_{Mn}$	mg/l	7	10.5	11.8	10.21	12.08
Nitrate	mg/l	45	0.75	1.99	1.35	1.87
Ammonia	mg/l	2	0.15	0.36	0.08	0.26
Nitrite	mg/l	33	0.007	0.28	0.011	0.023
Chloride	mg/l	350	6.2	8.0	7.8	8.3
Sulfate	mg/l	500	8.8	16.0	10.7	13.7
Hardness	meqv/l		0.65	0.79	0.73	0.83
TS	mg/l		58.4	93.8	77.7	86.8
Ignition loss	mg/l		31.8	49.2	33.4	41.4
Molybdene	mg/l	0.25	less	0.0025	-	$5*10^{-6}$
Copper	mg/l	1.0	0.04	0.09	0.006	0.02
Lead	mg/l	0.03	0.01	0.015	0.003	0.0037
Arsene	mg/l	0.05	less	0.01	0.01	0.01
Zinc	mg/l	1.0	0.13	0.17	0.01	0.04
Coli Bact.	pcs/l	1000	6200	$2.4*10^{6}$	500	$2.4*10^{6}$
Beryllium	mg/l	0.0002			-	-
Cadmium	mg/l	0.001			-	-
Cobolt	mg/l	0.1			0.02	0.06
Manganese	mg/l	0.1			0.01	0.02
Nickel	mg/l	0.1			-	0.02
Mercury	mg/l	0.0005			-	-

Appendix 7. 1(6) Drinking water quality in St. Petersburg, years 1991-1993. The figures represent the mean quality and maximum values of drinking water produced by five drinking water plants.

	Year 1993, january-august		Year 1992		Year 1991	
	Mean	Max.	Mean	Max.	Mean	Max
Colour	15	22	16	20	16	20
pH	6.8	7.0	6.7	7.0	6.8	7.2
Alkalinity, meqv/l	0.32	0.38	0.33	0.39	0.34	0.45
COD(Mn), mg O_2/l	5.6	6.4	5.6	6.7	4.9	6.8
COD(Cr), mg O_2/l	17.8	22.3	16.8	21.8	13.3	23.1
Oxygen, mg/l	13.0	15.3	12.5	15.1	11.9	15.3
Ammonia, mg/l	0.30	0.66	0.25	0.54	0.29	0.62
Nitrate, mg/l	1.89	3.52	1.82	2.45	1.43	2.66
Nitrite, mg/l	0.006	0.016	0.006	0.023	0.007	0.026
Chloride, mg/l	8.7	11.3	9.5	11.2	10.2	14.4
Sulphate, mg/l	15.0	22.6	17.5	38.4	15.3	24.7
Hardness, meqv/l	1.14	9.14	0.81	1.20	0.77	1.02
Oils, mg/l	0.05	0.05	0.05	0.05	0.08	0.50
Iron, mg/l	0.04	0.09	0.06	0.12	0.07	0.28
Aluminium, mg/l	0.20	0.54	0.22	0.75	0.29	0.45
Copper, µg/l	3	6	3	6	3	12
Nickel, µg/l	2	8	3	9	3	10
Zinc, µg/l	9	35	9	70	13	120
Cadmium, µg/l	1	1		1	6	10
Chromium, µg/l	10	10	10	10	10	10
Lead, µg/l		8				
Cobalt, µg/l	20	60	10	50	10	50
Residue chlorine, mg Cl_2/l	1.05	1.20	1.05	1.2	1.03	1.20

Appendix 7. 2(6) Drinking water quality in St. Petersburg, year 1991.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Petrogradsky drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	15	20	14	19	15	20	17	20	15	20
pH	6.7	6.9	6.7	6.8	6.8	7.0	6.9	7.2	6.7	7.0
Alkalinity, meqv/l	0.34	0.39	0.33	0.37	0.35	0.39	0.37	0.45	0.34	0.40
COD(Mn), mg O_2/l	4.6	6.4	4.5	5.8	4.7	6.2	5.4	6.8	5.3	6.6
COD(Cr), mg O_2/l	12.3	15.8	13.0	17.8	14.2	23.1	13.8	19.9	14.2	23.1
Oxygen, mg/l	11.9	13.5	12.2	14.7	11.7	15.3	12.3	13.9	11.4	14.0
Ammonia, mg/l	0.27	0.62	0.26	0.39	0.22	0.44	0.33	0.44	0.22	0.44
Nitrate, mg/l	1.53	2.66	1.27	1.94	0.28	0.45	0.31	0.45	0.28	0.36
Nitrite, mg/l	0.008	0.026	0.007	0.016	0.006	0.014	0.008	0.021	0.006	0.014
Chloride, mg/l	10.6	14.4	10.0	11.6	10.0	10.7	10.3	11.8	10.0	10.8
Sulphate, mg/l	15.0	23.8	15.8	20.4	16.4	24.7	14.0	20.9	15.2	22.3
Hardness, meqv/l	0.77	0.90	0.75	0.80	0.76	0.85	0.78	0.84	0.78	1.0
Iron, mg/l	0.09	0.16	0.05	0.16	0.08	0.28	0.10	0.22	0.05	0.11
Aluminium, mg/l	0.31	0.43	0.25	0.37	0.28	0.45	0.31	0.45	0.28	0.36
Copper, µg/l	3	7	4	8	4	12	4	7	3	6
Nickel, µg/l	3	10	2	10	2	10	3	10	3	10
Zinc, µg/l	19	120	11	20	12	20	11	16	11	20
Cadmium, µg/l	6	10	6	10	6	10	6	10	6	10
Chromium, µg/l	10	10	10	10	10	10	10	10	10	10
Cobalt, µg/l	10	50	10	20		10		10		10
Detergents, µg/l	8	12	12	30	11	18	14	20	9	13
Residue chlorine, mg Cl_2/l	1.00	1.20	1.09	1.20	1.04	1.20	0.97	1.20	1.07	1.20

Appendix 7. 3(6) Drinking water quality in St. Petersburg, year 1992.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Petrogradsky drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	15	18	15	20	16	20	18	20	15	19
pH	7.7	6.9	6.7	6.9	6.8	7.0	6.8	6.9	6.7	6.8
Alkalinity, meqv/l	0.33	0.39	0.31	0.35	0.34	0.37	0.35	0.39	0.32	0.37
COD(Mn), mg O_2/l	5.6	6.4	5.3	6.0	5.8	6.7	6.0	6.5	5.5	6.3
COD(Cr), mg O_2/l	15.5	20.8	17.4	20.8	15.7	21.6	17.9	21.8	17.7	21.8
Oxygen, mg/l	12.4	14.4	12.4	15.1	12.1	14.2	13.3	14.7	12.2	13.9
Ammonia, mg/l	0.15	0.46	0.18	0.36	0.36	0.50	0.36	0.54	0.21	0.32
Nitrate, mg/l	1.89	2.45	1.77	2.01	1.79	2.20	1.87	2.03	1.78	2.16
Nitrite, mg/l	0.007	0.023	0.004	0.009	0.007	0.021	0.006	0.010	0.006	0.021
Chloride, mg/l	9.8	11.2	9.7	11.0	9.3	10.4	9.4	10.4	9.4	10.3
Sulphate, mg/l	18.4	35.1	18.2	27.0	17.6	31.5	16.6	29.9	16.8	38.4
Hardness, meqv/l	0.82	1.15	0.80	1.20	0.82	0.95	0.80	0.90	0.82	1.20
Iron, mg/l	0.05	0.07	0.04	0.09	0.06	0.10	0.08	0.11	0.05	0.12
Aluminium, mg/l	0.16	0.25	0.17	0.43	0.25	0.49	0.26	0.47	0.24	0.75
Copper, µg/l	3	6	3	5	3	4	3	6	2	4
Nickel, µg/l	2	3	3	7	3	7	3	9	3	5
Zinc, µg/l	11	70	6	14	12	55	7	11	7	16
Cadmium, µg/l		1		1		1		1	1	1
Chromium, µg/l	10	10	10	10	10	10	10	10	10	10
Cobalt, µg/l	10	40	20	50	10	30	10	20	20	50
Detergents, µg/l	12	15	10	14	11	22	13	22	11	17
Residue chlorine, mg Cl_2/l	1.06	1.20	1.06	1.18	1.07	1.20	0.94	1.20	1.13	1.20

Appendix 7. 4(6) Drinking water quality in St. Petersburg, january-august 1993.

	Southern drinking water plant		Northern drinking water plant		Main drinking water plant		Petrogradsky drinking water plant		Volkovsky drinking water plant	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Colour	14	19	14	18	16	22	17	20	12	19
pH	6.7	6.8	6.7	6.8	6.8	6.9	6.9	7.0	6.7	7.0
Alkalinity, meqv/l	0.31	0.36	0.31	0.33	0.33	0.35	0.36	0.38	0.31	0.35
COD(Mn), mg O_2/l	5.3	6.2	5.4	6.2	5.7	6.4	5.9	6.1	5.6	6.2
COD(Cr), mg O_2/l	18.0	20.6	18.5	22.3	18.6	21.4	16.9	21.6	17.2	20.6
Oxygen, mg/l	12.9	15.2	12.7	14.8	12.3	14.6	14.3	15.3	12.6	14.5
Ammonia, mg/l	0.23	0.44	0.23	0.36	0.41	0.66	0.41	0.56	0.19	0.29
Nitrate, mg/l	2.04	3.52	1.80	2.67	1.74	2.46	2.17	2.71	1.70	2.58
Nitrite, mg/l	0.007	0.016	0.007	0.016	0.006	0.007	0.006	0.008	0.005	0.007
Chloride, mg/l	9.3	11.3	8.7	9.8	7.4	9.6	9.1	9.2	8.8	10.1
Sulphate, mg/l	14.9	22.6	15.5	22.5	14.5	21.8	14.8	17.4	15.5	22.0
Hardness, meqv/l	0.95	1.15	1.97	9.14	0.90	0.97	0.91	0.97	0.97	1.17
Iron, mg/l	0.05	0.09	0.03	0.05	0.04	0.05	0.05	0.06	0.04	0.05
Aluminium, mg/l	0.18	0.28	0.19	0.29	0.21	0.35	0.18	0.24	0.27	0.54
Copper, µg/l	3	6	3	6	2	4	3	4	2	5
Nickel, µg/l	3	8	2	3	2	4	2	3	3	5
Zinc, µg/l	9	23	10	24	12	35	7	8	6	9
Cadmium, µg/l	1	1		1	1	1	1	1	1	1
Chromium, µg/l	10	10	10	10	10	10	10	10	10	10
Cobalt, µg/l	30	50	10	10	20	60	20	30	20	60
Detergents, µg/l	9	15	12	22	10	13	9	14	10	14
Residue chlorine, mg Cl_2/l	1.10	1.19	1.01	1.17	0.99	1.12	1.06	1.10	1.12	1.20

Appendix 7. 5(6) Drinking water quality in two drinking water plants of St. Petersburg, september 1993.

	Southern drinking water plant	Main drinking water plant
Turbidity, FTU	1.3	1.0
Conductivity, mS/m	11.8	11.0
Alkalinity, meqv/l	0.33	0.34
pH	6.7	6.8
Colour	15	15
COD(Mn), mg O_2/l	4.7	5.3
Total nitrogen, µg/l	1000	930
Nitrate, µg NO_3-N/l	280	260
Nitrite, µg NO_2-N/l	<1.0	<1.0
Ammonia, µg NH_4-N/l	430	340
Total phosphorus, µg/l	7	8
Phosphate, µg/l	<1	<1
Chloride, mg/l	8.2	8.2
Total iron, µg/l	50	45
Iron, filtered sample, µg/l	17	18
Sulphate, mg/l	22	19
Faecal coliform bacteria (44 °C), 1/100 ml	0	0
Coliform bacteria (35 °C), 1/100 ml	0	0
Total hardness, meqv/l	0.04	0.04
Zinc, µg/l	2.6	1.8
Selenium, µg/l	0.49	0.45
Nickel, µg/l	0.81	0.82
Lead, µg/l	0.020	0.010
Copper, µg/l	1.6	1.3
Chromium, µg/l	0.65	0.64
Cadmium, µg/l	0.011	<0.005
Aluminium, µg/l	290	180
Arsene, µg/l	0.29	0.30
Barium, µg/l	14	14
Boron, µg/l	11	11
Manganese, µg/l	3.1	3.8
Natrium, µm/l	5.0	5.0

Appendix 7. 6(6) The Quality of Raw and Drinking Water Samples Taken by Kymi Water and Environment District 1992

		Point of sampling			
Parameter	Unit	Raw water (untreated) of Main Water Supply Plant	Distributed water (treated) from Main Water Supply Plant	Drinking water (Hotel St. Petersburg)	Drinking water (Politolog. institut dormitory 1)
Date		25.05.92	25.05.92	27.05.92	02.08.92
Temperature	°C	11	11	18	
pH		7,5	6,7	6,6	6,7
Conductivity	mS/m	10,2	11,4	11,3	10,4
Turbidity	FTU	1,1	1,1	1,8	0,9
Color	mgPt/l	35	20	35	15
Alkalinity	mmol/l	0,50	0,33	0,29	0,31
Total hardness	mmol/l	0,32	0,33	0,35	0,34
Suspended solids (SS)	mg/l	3,5	1,7	2,3	
COD_{Mn}	mgO_2/l	7,0	4,6	4,1	
$KMnO_4$-figure	mg/l	28	18	16	18
TOC	mg/l	7,6	5,9	5,6	
Nitrite+Nitrate (NO_2+NO_3-N)	mgN/l	0,28	0,29	0,37	0,34
Ammonium (NH_4-N)	mgN/l	0,038	0,36	0,20	0,35
Total phosphorus	µgP/l	22	9	8	
Chloride	mgCl/l	6,8	8,3	8,8	
Iron	mgFe/l	0,16	0,061	0,74	0,12
Manganese	mgMn/l	0,020	0,017	0,014	
Thermotolerant coliform bacteria (44°C)	CFU per 100ml			0	0
Total coliform bacteria (35°C)	CFU per 100ml	0	0	0	0
Faecal streptococci	CFU per 100ml				0
Fluoride	mgF/l	0,090	0,070	0,070	
Arsenic	mgAs/l	< 0,001	< 0,001	< 0,001	
Cadmium	mgCd/l	< 0,0001	< 0,0001	< 0,0001	
Lead	mgPb/l	< 0,001	< 0,001	< 0,001	
Chromium	mgCr/l	0,003	< 0,001	< 0,001	
Nickel	mgNi/l	< 0,001	< 0,001	< 0,001	
Aluminium	mgAl/l	0,130	0,320	0,330	
Copper	mgCu/l	0,003	0,002	0,002	
Zinc	mgZn/l	0,125	0,112	0,150	

Appendix 8. 1(3) Water quality in River Ohta (River Neva's tributary, discharging directly to Neva) in May-October, years 1990-1992.

	Year 1992			Year 1991			Year 1990		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Colour	53	59	76	55	81	89	35	74	85
pH		7.2		7.0	7.5	7.8	7.0	7.2	7.5
COD(Mn), mg O_2/l	11	14	19	13	17	19	13	16	20
Oxygen, mg/l	2.3	4.1	6.5	2.0	3.9	7.8	3.2	6.2	9.2
Ammonia, mg/l	0.14	2.8	4.1	1.7	3.1	5.5	1.1	1.7	2.0
Nitrate, mg/l	0.40	1.5	2.9	0.30	1.2	2.6	9.9	11	12
Nitrite, mg/l	0.14	0.90	1.6	0.14	0.30	0.48	0.27	0.43	0.58
Chloride, mg/l	24	32	70	26	38	60	19	30	36
Sulphate, mg/l	25	32	41	18	26	45	21	37	58
Oils, mg/l	0.30	1.0	3.6	0.40	0.60	1.6	0.05	0.10	0.16
Faecal coliform bacteria, 1/ml	13,000	320,000	$2.4 \cdot 10^6$	2,400	6,000	$2.4 \cdot 10^{12}$	7,000	610,000	$2.4 \cdot 10^6$
Iron, mg/l	0.22	0.48	0.60	0.30	1.4	2.6	0.50	0.88	1.4
Aluminium, mg/l									
Copper, µg/l									
Nickel, µg/l									
Zinc, µg/l									
Cadmium, µg/l									
Chromium, µg/l									
Lead, µg/l									
Cobalt, µg/l									

Appendix 8. 2(3) Water quality in River Slavyanka (River Neva's tributary, discharging directly to Neva) in May-October, years 1990-1992.

	Year 1992			Year 1991			Year 1990		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Colour	53	58	67	48	78	104			
pH	7.5	7.7	8.2	6.9	7.8	8.4	7.0	7.6	8.1
COD(Mn), mg O_2/l	13	28	54	15	23	38	11	24	36
Oxygen, mg/l	7.4	7.9	8.9	5.8	7.5	8.3	7.6	8.3	9.2
Ammonia, mg/l	0.52	4.0	7.8	0.39	2.2	3.9	1.3	4.2	6.5
Nitrate, mg/l	4.3	7.7	11	3.0	7.9	11	2.9	6.2	11
Nitrite, mg/l	0.004	0.34	0.69	0.033	0.35	0.79	0.10	0.58	1.2
Chloride, mg/l	32	39	45	18	33	52	16	26	44
Sulphate, mg/l	22	35	68	18	37	61	17	28	50
Oils, mg/l	0.004	0.08	0.40	0.01	0.29	0.40	0.01	0.01	0.016
Faecal coliform bacteria, 1/ml								$2.4 \cdot 10^6$	
Iron, mg/l	0.01	0.11	0.34	0.80	1.2	1.5	0.30	1.1	2.2
Aluminium, mg/l									
Copper, µg/l	0.006	0.02	0.068	0.01	0.02	0.035			
Nickel, µg/l				0.004	0.04	0.04		0.015	
Zinc, µg/l				0.05	0.21	0.36	0.003	0.30	0.71
Cadmium, µg/l				0.001	0.0015	0.002		0.001	
Chromium, µg/l									
Lead, µg/l				0.004	0.01	0.04			
Cobalt, µg/l									

Appendix 8. 3(3) Water quality in River Izhora (River Neva's tributary, discharging directly to Neva) in January-December, years 1990-1992.

	Year 1992			Year 1991			Year 1990		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Colour									
pH	7.8	8.2	8.4	7.7	7.9	8.0	7.4	7.7	8.4
COD(Mn), mg O_2/l									
Oxygen, mg/l	4.3	7.1	9.8	7.9	8.8	9.9	6.2	7.6	8.7
Ammonia, mg/l	4.4	4.9	13	2.2	4.4	7.3	1.9	3.8	9.6
Nitrate, mg/l	2.8	16	18	4.8	8.6	9.8	3.6	8.4	9.8
Nitrite, mg/l	0.038	0.09	0.25	0.06	0.10	0.19	0.04	0.085	0.18
Chloride, mg/l	34	45	60	42	46	57	43	50	60
Sulphate, mg/l	41	48	94	23	26	31	20	32	40
Oils, mg/l	0.30	0.52	0.60	0.30	0.44	0.60	0.37	0.42	0.65
Faecal coliform bacteria, 1/ml	7,000		700,000	2,400		24,000	700		700,000
Iron, mg/l	0.26	0.62	0.85	0.29	0.57	1.1	0.27	0.80	0.91
Aluminium, mg/l									
Copper, µg/l		0.11	0.15	0.038	0.06	0.10	0.01	0.04	0.07
Nickel, µg/l		0.007	0.023			0.01		0.06	0.12
Zinc, µg/l		0.022	0.15		0.0037	0.07		0.029	0.04
Cadmium, µg/l									
Chromium, µg/l		0.003	0.021		0.007	0.02		0.012	0.02
Lead, µg/l									
Cobalt, µg/l									

Appendix 9 Seasonal and annual phosphorus balance of Lake Ladoga

	Abbreviation	Winter	Spring	Summer	Autumn	Whole year
		No. of days: 121	No. of days: 47	No. of days: 106	No. of days: 91	No. of days: 365
OUTCOMES						
Phosphorus loss through lake outlet, kg/d	O	5,678.64	5,377.73	5,516.87	5,163.63	5,464.51
Gross sedimentation, kg/d	G	17,670.00	32,332.34	48,009.06	35,340.00	32,774.22
Change in the amount of phosphorus in the lake water, kg/d	dM/dt	-1,158.68	15,584.04	-2,493.68	-3,603.52	0,00
SUM		22,189.97	53,294.11	51,032.25	36,900.11	38,238.73
INCOMES						
External loading, kg/d	E	18,228.32	23,021.08	21,588.58	20,650.42	20,425.19
Internal loading, kg/d	I	3,961.65	30,273.03	29,443.66	16,249.69	17,813.54
SUM		22,189.97	53,294.11	51,032.25	36,900.11	38,238.73
Net sedimentation*, kg/d	N	13,708.35	2,059.31	18,565.39	19,090.31	14,960.68
Quotient N/E		0.75	0.09	0.86	0.92	0.73
Quotient I/E		0.22	1.32	1.36	0.79	0.87

*) Net sedimentation is defined as Gross sedimentation minus Internal loading.

In this case Ladoga's gross sedimentation have been estimated undirectly by using values found in Finnish and international literature, because experimentally determined values for gross sedimentation were not available.

It must be noted that the figures in the table have not been rounded because of reasons connected only with computation technique and the exact balance of the calculation. The true accuracy of figures extends at the most to two first significant numbers of each presented value.

Appendix 10

Finnish raw water classification of surface water

Substance	Limits of values in different classes				
	I Excellent	II Good	III Satisfactory	IV Poor	V Unsuitable
Maximum temperature, °C	< 15	15-20	20 - 25	20 - 25	> 25
Visibility depth, m	> 3.5	>2.5	1.5 - 2.5	0.5 - 1.5	-
COD_{Mn}, O_2 mg/l	< 3.8	3.8-10	10 - 20	20 - 30	> 30
Colour, standard scale	< 15	15-70	70 - 150	150 - 200	> 200
pH	6.5 - 7.5	-	-	-	-
Oxygen O_2, % of saturation value	80 - 110	80-110	60 - 125	40 - 150	<40 or >150
Turbidity, FTU	< 1	-	-	-	-
Iron Fe, µg/l	< 200	200-500	500-2,000	2,000-5,000	-
Manganese Mn, µg/l	< 10	10 - 30	30 - 100	100 - 1,000	>1,000
Total phosphorus P, µg/l	< 10	10 - 25	25 - 50	50 - 100	> 100
A-chlorophyll, µg/l (growing season's mean value)	< 2	2 - 5	5 - 20	20 - 100	> 100
Total coliforms (35 °C), pcs/100 ml	only occasionally and <10	< 50	50 - 100	100-1,000	> 1,000
Faecal coliforms (44 °C), pcs/ 100 ml	only occasionally and <3	< 10	10 - 50	50 - 500	> 500
Wet weight of phytoplankton, mg/l (growing season's mean value)	-	< 0.5	0.5 - 2	2 - 10	> 10
Total bacteria (22 °C), pcs/ml	-	-	< 1,000	1,000-10,000	>10000
Ammonia NH_4, µg/l	-	< 100	100 -500	500-2,000	> 2,000
Nitrites NO_2, µg/l	-	-	< 50	50 - 100	> 100
Nitrates NO_3, mg/l	-	-	-	< 30	> 30
Lignin NaLS, mg/l	-	< 2	2 - 5	5 - 10	> 10
Phenols, µg/l	-	-	< 2	2 - 10	> 10
Mineral oils, µg/l	-	-	< 50	50 - 100	> 100
Conductivity, mS/m	-	-	-	20 - 40	> 40
Chlorides Cl^-, mg/l	-	-	-	50 - 200	> 200
Sulphates SO_4, mg/l	-	-	-	70 - 150	> 150
Arsenic As, µg/l	-	-	-	< 50	> 50
Mercury Hg, µg/l	-	-	-	< 2	> 2
Cadmium Cd, µg/l	-	-	-	< 5	> 5
Chromium Cr(VI), µg/l	-	-	-	< 50	> 50
Lead Pb, µg/l	-	-	-	< 50	> 50
Cyanides CN, µg/l	-	-	-	< 50	> 50

Appendix 11. 1(2) Annuity costs of investments for raw water transfer and treatment systems for different raw water alternatives

Annuity factor can be calculated according to following formula:

$$\frac{i(1+i)^n}{(1+i)^n - 1}$$

n = amortization time, following has been used:
- machinery 15 years
- buildings 30 years
- tunnels, channels and pipelines 50 years

i = calculation interest (6 % used)

Finnish marks has been changed to USD by exchange rate 0.17 (1 USD = 5.8 FIM).

River Neva

Subproject	Machinery		Buildings		Long lasting parts		Total
	mUSD	mUSD/a	mUSD	mUSD/a	mUSD	mUSD/a	mUSD/a
Construction of raw water transfer system	1) 3 2) 13 3) 15	1) 0.3 2) 1.3 3) 1.5	1) 7 2) 27 3) 35	1) 0.5 2) 2.0 3) 2.5	1) 20 2) 80 3) 120	1) 1.3 2) 5.1 3) 7.6	**1) 2.1** **2) 8.4** **3) 11.6**
Renovation of present water treatment plants	120	12.4	180	13.1	-	-	**25.5**
Construction of extra capacity	27	2.8	53	3.9	-	-	7.7
Total	**1) 150** **2) 160** **3) 162**	**15.5** **16.5** **16.7**	**240** **260** **268**	**17.5** **19.0** **19.5**	**20** **80** **120**	**1.3** **5.1** **7.6**	**34** **42** **45**

(1 Raw water is transferred to intake of MWTP from intake of SWTP

(2 Raw water to all intakes is transferred above the mouth of River Izora

(3 Raw water reservoir for 7 days retention time is excavated and raw water transferred from there to WTP intakes

Lake Ladoga

Subproject	Machinery		Buildings		Long lasting parts		Total
	mUSD	mUSD/a	mUSD	mUSD/a	mUSD	mUSD/a	mUSD/a
Construction of raw water transfer system	70	7.2	110	8.0	300	19.0	**34.2**
Renovation of present water treatment plants	20	2.1	30	2.2	-	-	**4.3**
Construction of extra capacity	15	1.6	35	2.5	-	-	**4.1**
Total	**105**	**10.9**	**175**	**12.7**	**300**	**19.0**	**43**

Appendix 11. 2(2) Annuity costs of investments for raw water transfer and treatment systems for different raw water alternatives

River Vuoksi

Subproject	**Machinery**		**Buildings**		**Long lasting parts**		**Total**
	mUSD	mUSD/a	mUSD	mUSD/a	mUSD	mUSD/a	mUSD/a
Construction of raw water transfer system	100	10.3	160	11.6	500	31.7	**53.6**
Renovation of present water treatment plants	20	2.1	30	2.2	-	-	**4.3**
Construction of extra capacity	15	1.6	35	2.5	-	-	**4.1**
Total	**135**	**14.0**	**225**	**16.3**	**500**	**31.7**	**62**