CFD Simulations on a CSO in Toronto

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ABSTRACT

Combined sewers are common in older parts of Toronto as in many other big cities in the western world. If the combined sewers fail with their purpose they may cause high flood peaks during rainfalls with sewer backups and basement flooding as a result. The high flows may also cause problems with biological treatment at the treatment plants. The most common solution of these problems is to furnish systems with a discharger, were the extra sewage can overflow to a recipient. Combined sewer overflows, CSO's are however recognized as a major source of wet weather pollutions, with adverse effects on receiving waters.

Chemically aided settling in CSO's may reduce the adverse effects on receiving waters. This is a technique of great interest and it's being under research by the Urban Water Management Project, at the Aquatic Ecosystem Management Research Branch, National Water Research Institute, Environment Canada. The project consists a full scale testing at a CSO at North Toronto Treatment Plant (NTTP) in Toronto, Canada. The project also includes a laboratory model and computer models of the same CSO.

The aim of this master thesis has been to examine the directions, velocities and mixing of current in the CSO at the NTTP, in order to determine if the system is appropriate for chemically aided settling. For answering this question we have used a CFD-program, to simulate flows, mixing and current in the North Toronto CSO-system. In our model we have used Fluent 5.0 as a solver and Gambit as pre-processor.

The simulations show that most of the flow goes through tank 1, and least through tank 3. There is a good plug flow in the tanks, except from the first 10 meters, were it's a bit disturbed from the inlets. The mixing would be better if the jets didn't stir up to the surface and went directly into the tanks. The flow from the different pipes reach different tanks, and use different parts of the mix channel. Only parts of the flow in the mixing channel are getting well mixed.

To make the system more appropriate for chemically aided settling, it would be wise to put up a screen that kills the jets before they reach the tanks, to improve the plug flow in the tanks and create a better mixing in the mix channel. It would be good to increase the openings in tank two and three to get a better distribution between the tanks. Use a conventional mixing system for the polymer, with channels by the surface and mixing under weir, instead of pipes. Use the favour of the high elevation down to the Don River by changing the elevation of the weirs between the CSO tank and the mix channel and between the tanks and the storm water tanks.

1 INTRODUCTION

Water is essential for most life on our planet. Water is one of the few compounds that can exist as a liquid, gas or a solid within the narrow temperature range of life. Water occurs in six general forms in the biosphere: vapor, fresh surface water, fresh groundwater and snow. Only a small piece of the water is available as fresh liquid water, the rest of the water is located in oceans and seas. The atmosphere, with all of its clouds, contains only 0.035% of the Earth's fresh water [4].

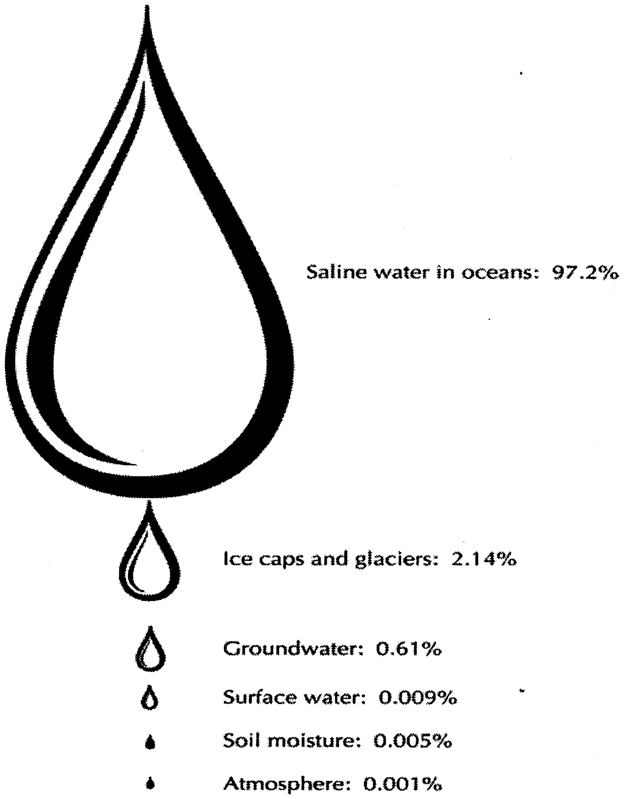


Fig. 1.1. The world's distribution of water. Fetter, C.W. (1994) Applied hydrology, third edition, page 4, fig 3.

Sadly, it seems like we have been taken fresh water for granted and our pollutants have contaminated much of our fresh water supplies. It might sometimes seem like we need some new water, but we know from experience that we have to live with the water that we have, and that the renewing of water is small.

This report is Robert Furén's and Ola Lagerkvist's master thesis at the department of Civil Engineering at Chalmers University of technology in Gothenburg Sweden. The purpose of this work is to support Dr Jiri Marsalek with determining flows and mixing at a Combined Sewage Overflow arrangement, CSO, in Toronto, Canada. Dr Jiri Marsalek is the Chief of the Urban Water Management Project, at the Aquatic Ecosystem Management Research Branch a department under the National Water Research Institute, Environment Canada. The work contents Computational Fluid Dynamic calculations, CFD, on the CSO with storage basins and other facilities of interest

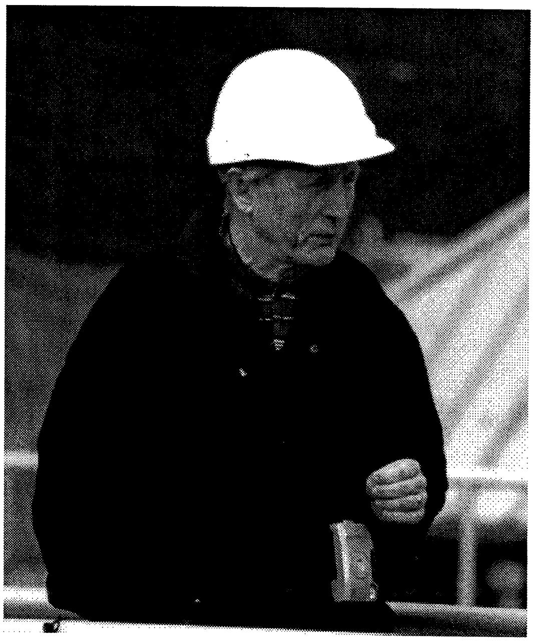


Fig. 1.2. Dr Jiri Marsalek in action. Photo by Robert Furén.

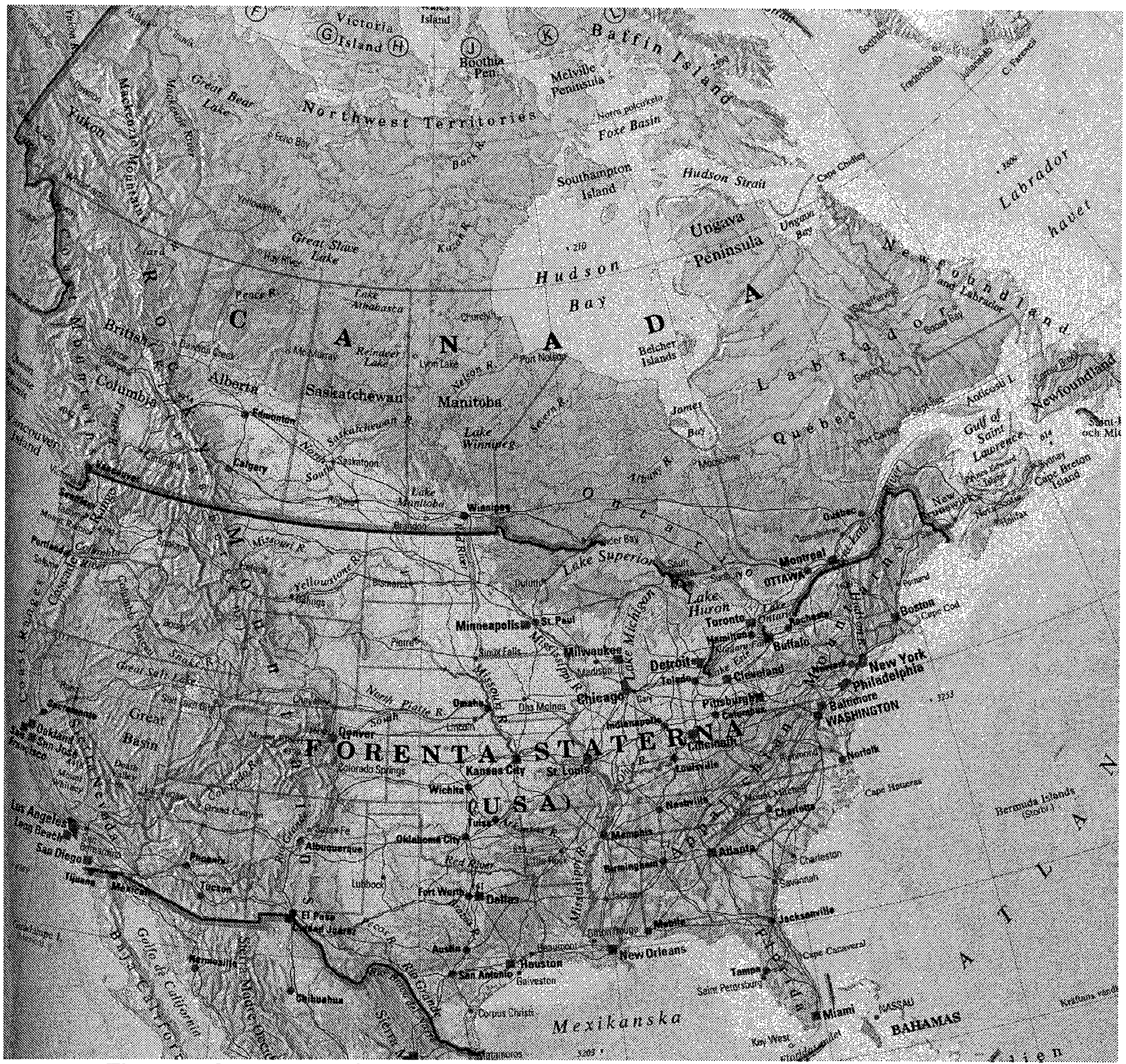


Fig. 1.3. Canada, half a continent. (Bonniers stora världs atlas, 1998, Bonnier lexikon.)

1.1 Background

Sewers are the part of the system for transportation of sewage to the sewage treatment plant, and to remove runoff as quickly as possible. Normally, when building sewage systems today, one usually try to separate storm water with conventional sewage, this because of its different characteristic and flow variation. But still combined sewers, are common in the older parts of Toronto, as in many other cities in the western world. If the combined sewers fail with their purpose they may cause high flood peaks during rainfalls with sewer backups and basement flooding as a result. High flows during rainfalls may also cause problems with biological treatment at the treatment plants, since the lack of "food" and toxic substances can kill the bacteria's [1].

The most common solution, to the problems associated with the combined sewage systems, is to furnish the systems with a discharger, were the extra sewage can overflow, to a recipient. In a combined system those dischargers are called CSO: s, Combined Sewage Overflow. This project is about a CSO-facility like this, in Toronto, Canada.

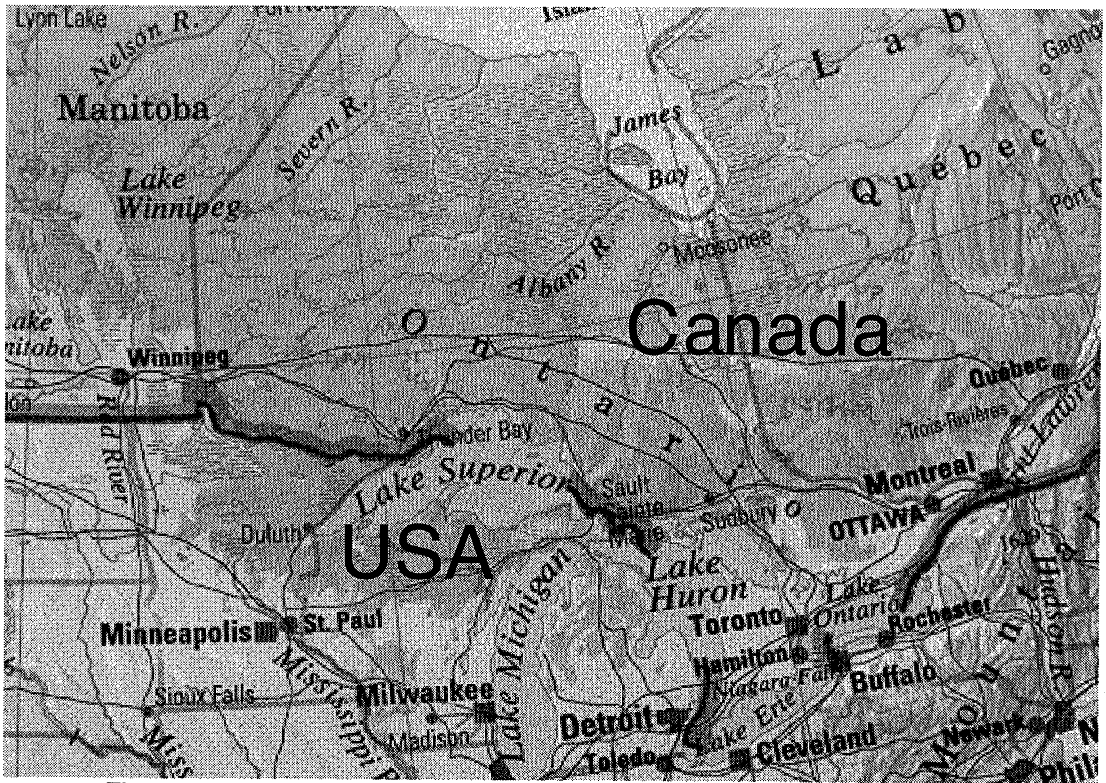


Fig. 1.1.1. Toronto, Canada, in The Great lakes basin. (Bonniers stora världs atlas, 1998, Bonnier lexikon.)

1.2 Problem description

The City of Toronto's Board of Public Health posts signs warning that swimming in local beaches may be hazardous to your health because of bacterial contamination of the water. This complex problem can be traced to many sources including storm water run-off containing animal excrement from fields and parks, discharge from illegal toilets connected to the storm sewers, and from overflows from old combined sanitary and storm sewers during heavy rainfalls. [2]

The CSO at The North Toronto Treatment Plant is supposed to discharge the combined sewage trunk that passes by the Don Valley in Toronto. The CSO consists of several storage basins between the combined trunk system and the recipient. The problem with the facilities is that the storage basins are in lack of capacity and the sensitivity of the recipients.

Because the costs of rebuilding a system like this and today's environmental requirements, Dr Jiri Marsalek are studying possibilities of adjusting the CSO in North Toronto for a better function and to fit our requirements. A polymer that speed up the settling process is on the agenda. The problem with the polymer is that it can be toxic for biological life below the recipient, if over dosed. The project can be summarized in four steps:

1. At the first step, the North Toronto Treatment Plant, has been complemented with a polymer dosing system, level measurer have been installed and a survey been made. In the first part real measurements has been taken at the CSO in north Toronto.
2. The second part is to build a scale model in the laboratory of CCIW, in Burlington, Ontario. In this scale model one can measure flows a make a study of mixing, particle tracking, and so on.
3. The third part is to simulate the construction with a computer model, in purpose to make predictions about the future. Two different models have been made for this project, one with Phoenix and one with Fluent. The Phoenix model has been doing modeling of real time flows. The Fluent model has been modeling flows and mixing.
4. The fourth part is to evaluate the results from the first parts and put them together, for new results, to compare and the different models and to value their results.

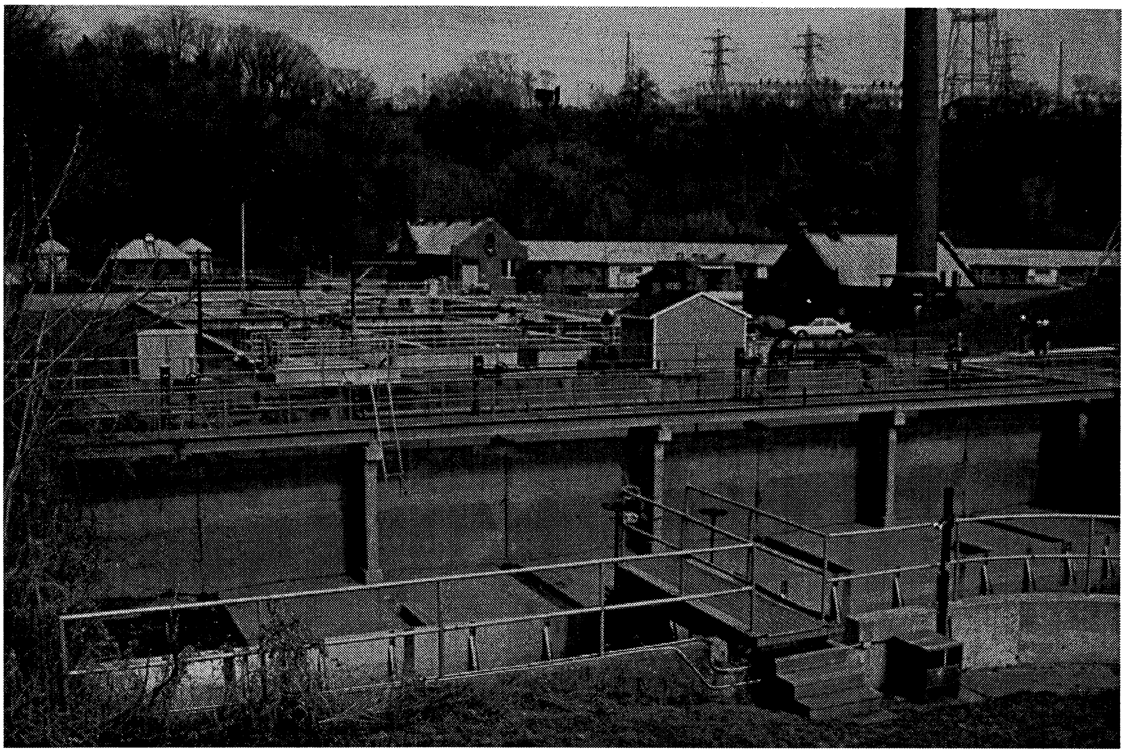


Fig. 1.2.1.The North Toronto Treatment Plant (NTTP). Photo: Robert Furén.

Below you can se two sketches of the CSO facility, the first one is a cross section. The lower sketch is supposed to be the CSO facility from above. You can see the inlet tank to the far right, with the four mixing pipes, leading to the mix channel. The three big tanks are the storage basin and the thinner to the left is the outlet channel.

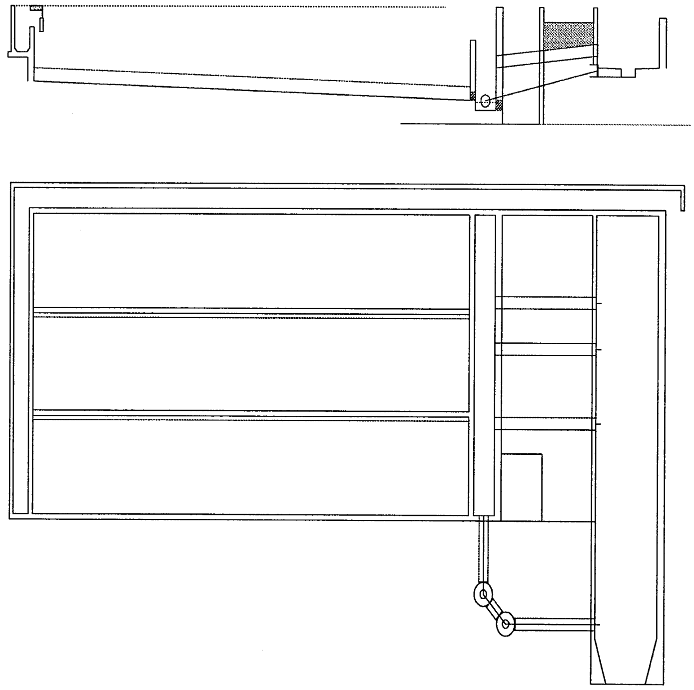


Fig. 1.2.2. Sketch of the North Toronto CSO, above in profile and below from the side. (Quintin Rochfort)

1.3 Aim and Purpose

Our part of the project is mainly contained in part 3, above. We should use the Fluent model to simulate the flows and dispersion of pollutants in the North Toronto CSO-system. The purpose is to find out the hydraulic function of the system. We aim to find out weather the system is well mixed or not, and for witch parts of the system. The reason is to find out if it might be possible to use the polymer, with a variable dosage during wet weathers instead of using a safe and lower level during the whole event.

2 ECOSYSTEMS

Our ecosystems are today exposed to gradual changes in climate, nutrient loading, habitat fragmentation or biotic exploitation. An ecosystem consists of the organisms, their environment, and the interactions which takes place between them demarcate by a certain boundary. It's a dynamic and very complex system. Nutrients are continually recycled within the ecosystem whilst energy flows through it. Different ecosystems have different stability, and different capacity. Nature is usually assumed to respond to gradual change in a smooth way. However sudden drastic switches to a contrasting state can interrupt smooth change and diverse events can trigger such shifts. This suggests that strategies for sustainable management of ecosystems should focus on maintaining resilience.

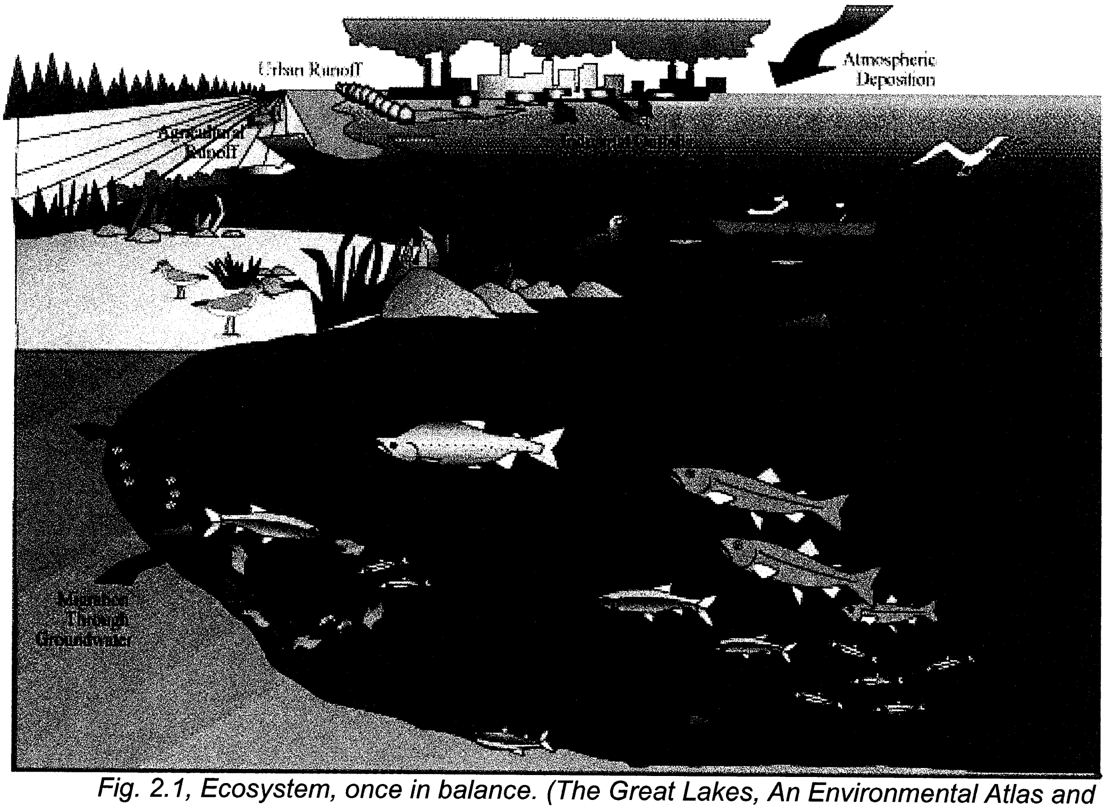


Fig. 2.1, Ecosystem, once in balance. (The Great Lakes, An Environmental Atlas and Resource Book, Government of Canada, Toronto, Ontario and United States Environmental Protection Agency, Great Lakes National Program Office Chicago, Illinois. Third edition 1995)

In natural ecosystems, nature prevents pollution by recycling materials at the same rate at which they are produced. Human cultures have accelerated the production of materials resulting in their accumulation in the atmosphere, waters and soils of the earth.

In the past our waters were a convenient place to get rid of undesirable materials produced by humans, like these waters would eliminate these undesirables. The result of dumping untreated wastes into our ecosystems was increased risk of human disease and death of aquatic life. In tend to break this trend; man finally realized that we have to protect our global ecosystems. [3]

2.1 The hydrological cycle

The foundation for understanding ecosystems with water, is the hydrological cycle. Water is a renewable resource that continually replenished in ecosystems through the hydrologic cycle. The hydrologic cycle describes the circulation of water as it evaporates from the Earths surface, moves into the atmosphere to form clouds, condenses as rain, snow or hail and returns to the earth as precipitation where it enters into soils, living organisms, lakes and streams. The cycle is completed as water returns to the atmosphere as vapor and form clouds.

The hydrologic cycle is driven by solar energy, which changes liquid water into vapor, through evaporation, and the force of gravity that causes liquid water to flow downhill were it joins rivers and streams which eventually lead into large lakes and oceans. Gravity also plays an important role in returning water from the atmosphere to terrestrial aquatic reservoirs. The amount of water vapor the atmosphere can hold is dependent on air temperature. Warm air can hold larger quantities of water vapor than cold air. If the water vapor in the air exceeds the saturation point, condensation occurs and water droplets become too large to remain suspended in the air and they fall to the earth as rain, sleet, hail or snow.

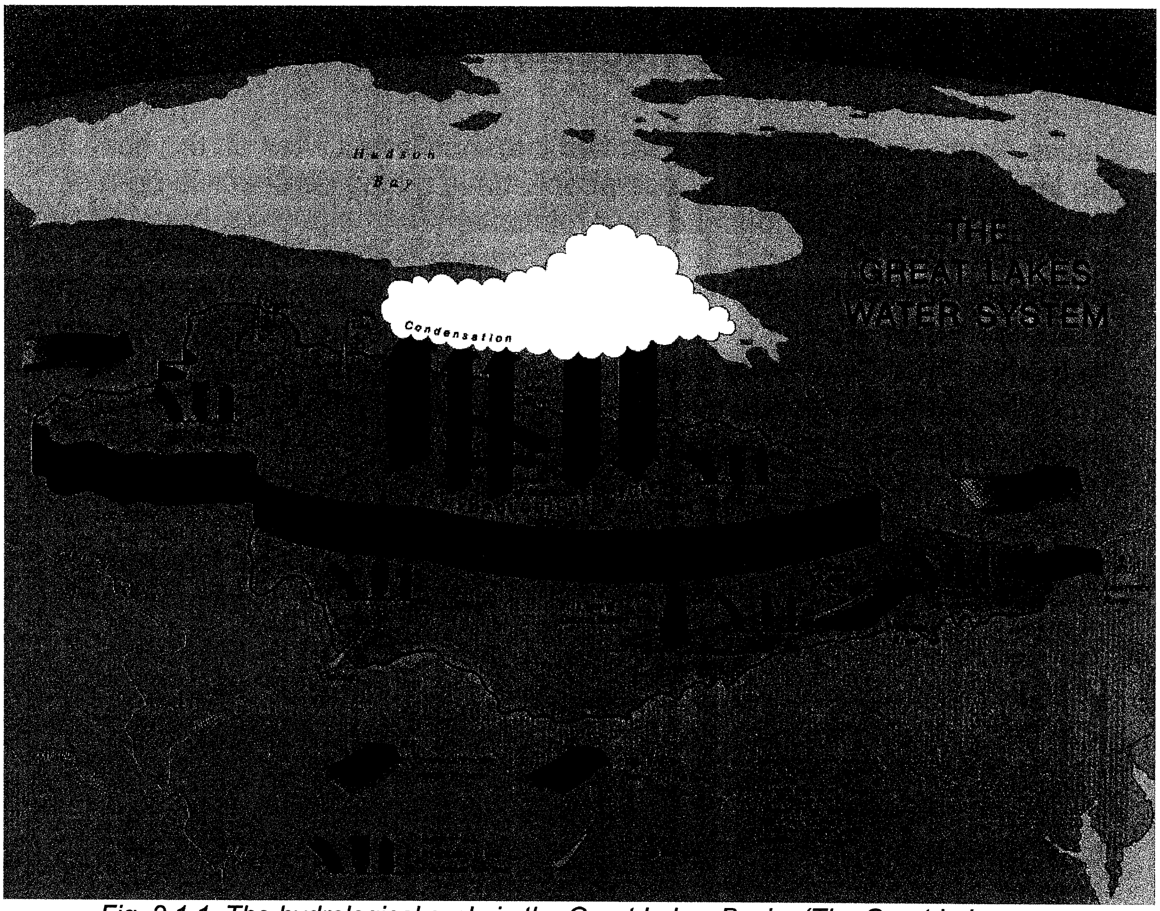


Fig. 2.1.1. The hydrological cycle in the Great Lakes Basin. (The Great Lakes, An Environmental Atlas and Resource Book, Government of Canada, Toronto, Ontario and United States Environmental Protection Agency, Great Lakes National Program Office Chicago, Illinois. Third edition 1995)

To understand how to attack today's problem with polluted water, it is essential to understand the hydrological cycle. The important thing is that water just change its phases, old polluted water don't disappear and get replaced by new water. [4] Like in most other cycles it's important that the cycle stay in balance, and to realize that anything added to the cycle will stay there, and this is where we, humans, are getting involved. Our living, today, are with lack of environmental respect. [4] There are many ways of working for better environment, but in this report we will focus on, a small pat of the hydrological cycle, just before the water reach the recipient after visiting our technical system.

2.2 The great lakes ecosystem

Native Americans' ancestors advanced into the Great Lakes on the heels of the last receding glaciation. These people have a long perspective born of their culture's several-thousand-year relationship with the area. After millennia of living in the watershed, European explorers arrived to "discover" their homeland. Men looking for a western route to China, surprised by the sweet seas they found, leading to treasures far beyond their original expectations. By the late 1800s and early 1900s, the Great Lakes area had become an industrial center with crossroads of the North American continent, providing copper, iron, lumber and cheap transportation. In the last half of the 20th century, the still wild and beautiful natural areas around much of the Great Lakes have been discovered by city-weary souls seeking renewal and revitalization. After nearly three centuries of extractive use, taking away what we want, the human species is beginning to see the Great Lakes ecosystem and it's values.

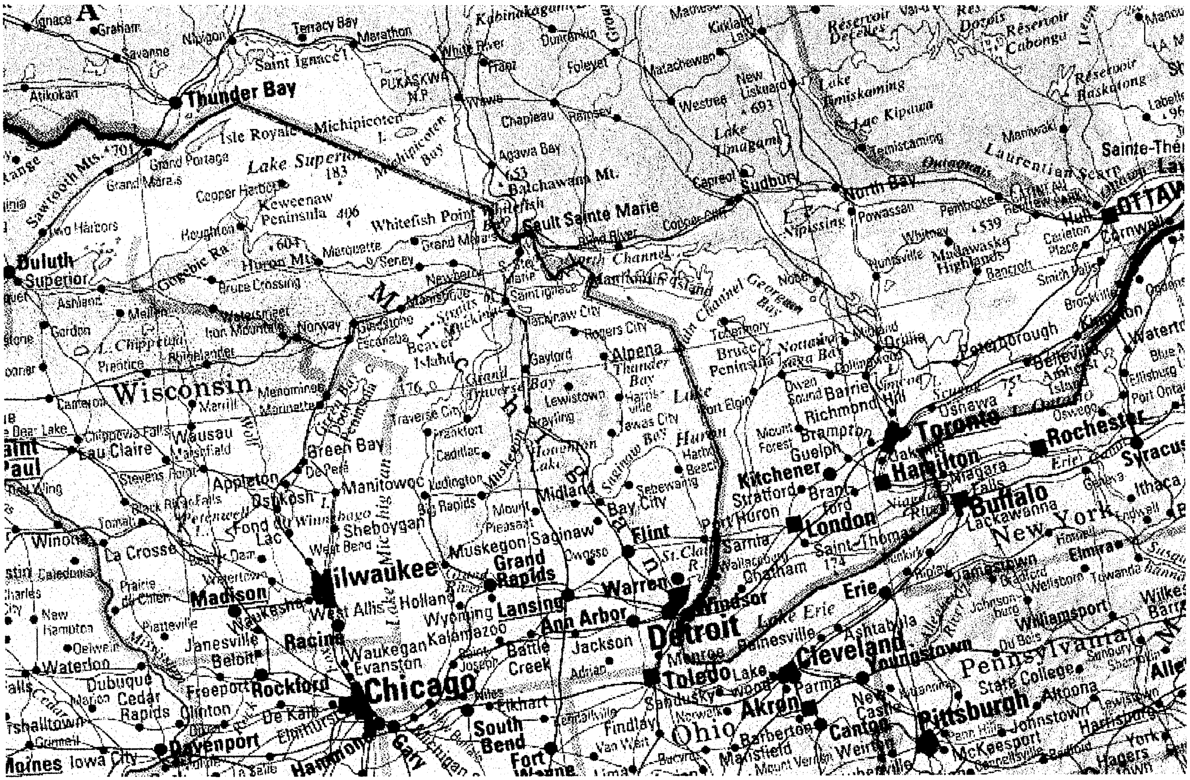


Fig. 2.2.1 The Great Lakes, on the boarder of two nations. (Bonniers stora världs atlas, 1998, Bonnier lexikon.)

The Great Lakes water system is of a great magnitude. Surrounded by two nations, a Canadian province, eight American states, the lakes contain about 23,000 km^3 (5,500 cu. mi.) of water, covering a total area of 244,000 km^2 (94,000 sq. mi.) The Great Lakes are the largest system of fresh surface water on earth, containing roughly 18 percent of the world supply. Only the polar ice caps contain more fresh water.

In spite of their large size, the Great Lakes are sensitive to the effects of a wide range of pollutants. The sources of pollution include the runoff of soils and farm chemicals from agricultural lands, the waste from cities, discharges from industrial areas and so on. The large surface area of the lakes also makes them vulnerable to direct atmospheric pollutants that fall with rain or snow and as dust on the lake surface.

Outflows from the Great Lakes are relatively small in comparison with the total volume of water, less than 1 percent per year. Pollutants that enter the lakes are retained in the system and become more concentrated with time.

Because of the large size of the watershed, physical characteristics such as climate, soils and topography vary across the basin. To the north, the climate is cold and the terrain is dominated by granite bedrock, the Canadian Shield. In the southern areas of the basin, the climate is much warmer. The soils are deeper with layers or mixtures of clays, silts, sands, gravels and boulders deposited as glacial drift or as glacial lake and river sediments. The lands are usually fertile and can be readily drained for agriculture. The original deciduous forests have given way to agriculture and sprawling urban development.

Although part of a single system, each lake is different. In volume, Lake Superior is the largest. It is also the deepest and coldest of the five. Superior could contain all the other Great Lakes and three more Lake Erie's. Because of its size, Superior has a retention time of 191 years. Retention time is a measure based on the volume of water in the lake and the mean rate of outflow. Most of the Superior basin is forested, with little agriculture because of a cool climate and poor soils. The forests and sparse population result in relatively few pollutants entering Lake Superior, except through airborne transport.

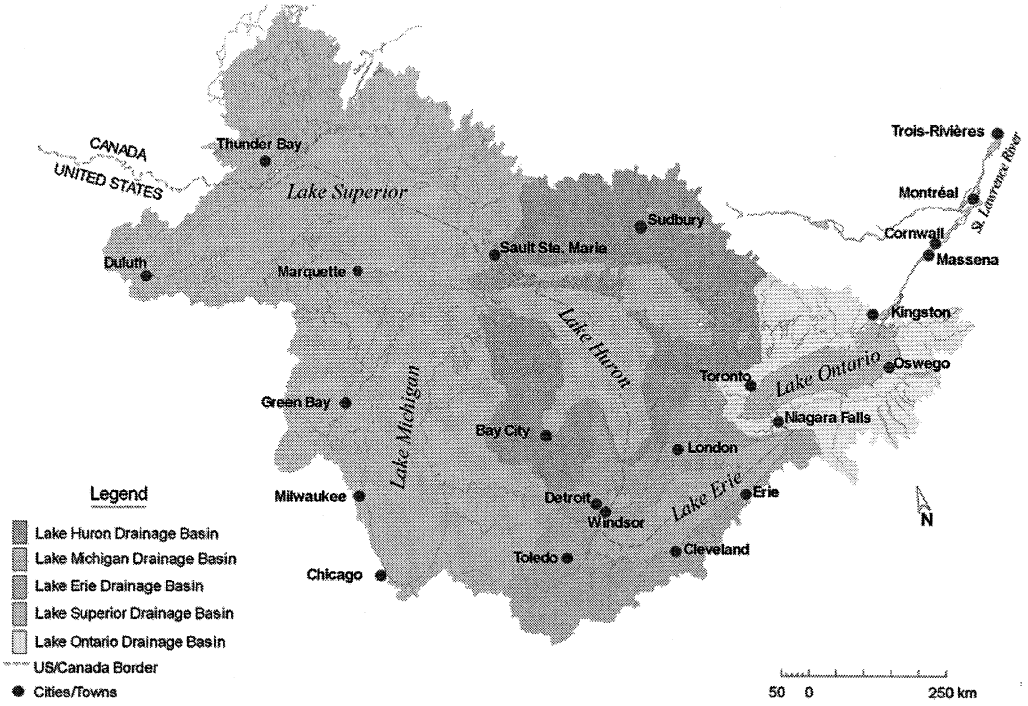


Fig. 2.2.2, the great lakes drainage basin (Environment Canada, 1999. URL: http://www.on.ec.gc.ca/glimr/maps-e.html , 2002-03-04)

Lake Michigan is the second largest and the only Great Lake entirely within the United States. The more temperate southern basin of Lake Michigan is among the most urbanized areas in the Great Lakes system. It contains the Milwaukee and Chicago metropolitan areas that are home to about 8 million people or about one-fifth of the total population of the Great Lakes basin.

Lake Huron, which includes Georgian Bay, is the third largest of the lakes by volume. Many Canadians and Americans own cottages on the shallow, sandy beaches of Huron and along the rocky shores of Georgian Bay. The Saginaw River basin is intensively farmed and contains the Flint and Saginaw-Bay City metropolitan areas. Saginaw Bay, like Green Bay, contains a very productive fishery.

Lake Erie is the smallest of the lakes in volume and is exposed to the greatest effects from urbanization and agriculture. Because of the fertile soils surrounding the lake, the area is intensively farmed. The lake receives runoff from the agricultural area of south western Ontario and parts of Ohio, Indiana and Michigan. Seventeen metropolitan areas with populations over 50,000 are located within the Lake Erie basin. Although the area of the lake is about 26,000 km^2, the average depth is only about 19 metres. It is the shallowest of the five lakes and therefore warms rapidly in the spring and summer, and frequently freezes over in winter. It also has the shortest retention time of the lakes, 2.6 years.

The modern history of the Great Lakes region, from discovery and settlement by European immigrants to the present day, can be viewed not only as a progression of intensifying use of a vast natural resource, but also as a process of learning about the Great Lakes ecosystem. At first it was a matter of making use of the natural resources of the basin while avoiding its dangers, later it was learned that abuse of the waters and the basin could result in great damage to the entire system. Toxic contaminants pose a threat not only to aquatic and wildlife species, but to human health as well, since humans are at the top of many food chains.

Humans are part of and depend on the natural ecosystem of the Great Lakes, but may be damaging the capacity of the system to renew and sustain itself and the life within it. Protection of the lakes for future use requires a greater understanding of how past problems developed, as well as continued remedial action to prevent further damage.

2.2.1 Lake Ontario

As we in this project will work with Lake Ontario, we will take an extra look at the lake. It is slightly smaller in area, much deeper than its upstream neighbour, Lake Erie, with an average depth of 86 metres and a retention time of about 6 years. Major urban industrial centres, such as Hamilton and Toronto, are located on its shore. The U.S. shore is less urbanized and is not intensively farmed, except for a narrow band along the lake.

Fig. 2.2.3. Lake Ontario. (Bonniers stora världs atlas, 1998, Bonnier lexikon.)

Lake Ontario, with its abundant natural resources and physical attractions, is a vital center for the almost eight million Canadians and Americans who live within its basin. It is of great import to remember that lake Ontario is the last lake of the great lakes before reaching the St. Lawrence River that leads in to the Atlantic.

2.3 The Toronto region watersheds

A watershed includes all of the lands draining into a lake or river system, and in the Greater Toronto Region, ultimately into Lake Ontario. In the Toronto Region we have nine important watersheds, Etobicoke Creek, Mimico Creek, The Humber River, The Don River, Highland Creek the Rouge River, Petticoat Creek, Duffins Creek and Carruthers Creek. The CSO in North Toronto has the Don River as recipient.

2.3.1 The Don River

The Don River is contaminated by runoff from urban pavements but also from CSO overflow's. Bacteria levels is quite high the Don watershed, particularly during wet rainy periods. Untreated human sewage still occasionally flows into the Don River from combined sewers. During rainfalls these combined sewers exceed their capacity and overflow into the river, with raw sanitary wastes and dirty storm water.

The storm water is the primary source of pollution in the Don River. It enters the Don and its tributaries through 1,185 outfalls and makes up 71% of the river's total flow. Storm water carries everything that washes off the streets, expressways, shopping plazas, driveways, front yards, golf courses, and farm fields, directly and untreated into the river. [1] It is of great import to remember that The Don River is an important recreation area in Toronto and that fishes and other aquatic life usually need cleaner water than humans do. [5]

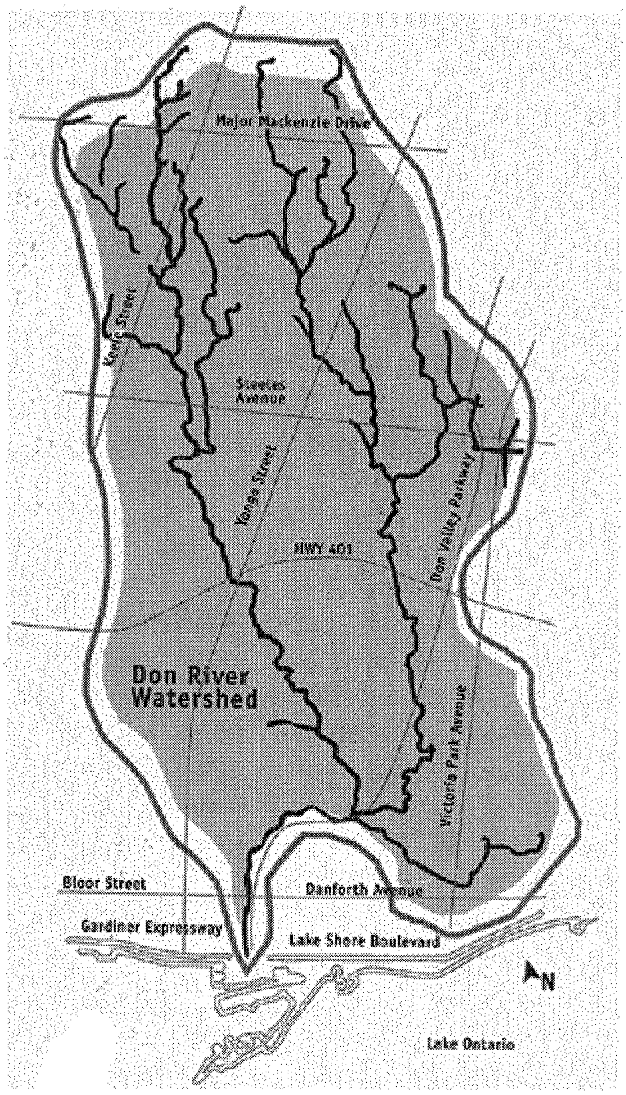


Fig. 2.3.1.1. The Don River water shed. (Environment Canada, 1999. URL: http://www.on.ec.gc.ca/glimr/maps-e.html, 2002-03-04)

3 POLLUTIONS

The part of human impact on nature in this project is focused on water and the problems associated with this impact are here called pollutions. Historically, the primary reason for water pollution control was prevention of waterborne disease

When an area is urbanized and a city with suburbs is built in a watershed, the water system and the natural water flow is changed forever. Paved surfaces, rooftops, roads, sidewalks, plazas and parking lots prevent rainwater from seeping into the ground and making its way to the river naturally. Instead gutters and underground storm drains remove rainfall from the area into the nearest stream very quick. The watercourse responds to this sudden influx by rising rapidly, and making life difficult for fish and other aquatic life. The opposite extreme may occur during dry weather.

Humans can acquire bacterial, viral and parasitic diseases through direct body contact with contaminated water as well as by drinking the water. This is usually attributed to the common practice of combining storm and sanitary sewers in urban areas. Although this practice has been discontinued, existing combined sewers contribute to contamination problems during periods of high rainfall and urban runoff. At these times, sewage collection and treatment systems cannot handle the large volumes of combined storm and sanitary flow. The result is that untreated sewage, diluted by urban runoff, is discharged directly into waterways.

Remedial action can be very costly if the preferred solution is replacement of the combined sewers in urban areas with separate storm and sanitary sewers. However, alternative techniques such as combined sewer overflow retention for later treatment can be used, greatly reducing the problem at lower costs than sewer separation. [6] Beach closures have become more infrequent with improved treatment of sewage effluent. [2]

3.1 Water pollutions in the Great Lakes

In considering pathways of pollution, it is important to recognize that in the case of the Great Lakes, regardless of whether pollutants are diluted by large stream flows or temporarily stored on sediment particles on stream bottoms, they will eventually reach the lakes and add to the total burden. Because the lakes respond to total quantities of persistent substances as well as localized concentrations, it is important to understand the total loading of pollutants to each lake from all pathways. This knowledge, together with bioaccumulation factors, can translate loadings into predictable levels in biota.

In order to eliminate the problem of water related pollution, sewage treatment facilities are designed and constructed to treat water prior to being released into our natural waterways. Sewage entering a treatment plant may contain hundreds or thousands, of pollutants such as human waste, paper, soap, detergent, dirt, cloth, food residue, micro organisms, industrial wastes, storm water, oil, fertilizers, household chemicals, etc. The problem of removing all of these pollutants is immense. The primary function of sewage treatment is to remove organic wastes which when discharged into natural waters may cause disease and reduces the availability of dissolved oxygen needed by aquatic organisms. Nature it self recycles materials via organisms such as bacteria and fungi which breakdown dead organic matter into more simple substances. When organic material is added to aquatic systems the number of decomposers increase exponentially and oxygen concentrations decrease until so little is available that other aquatic organism die.

The major types of water pollutants can be subdivided into eight different categories: [8]

- Nutrient Pollution.
- Organic nutrients from feedlots, sewage and some industries such as paper mills and meatpacking plants.
- Inorganic nutrients including nitrogen, phosphorus, iron, sulphur, sodium, and potassium.
- Infectious Agents from untreated sewage, animal wastes, and meatpacking plants.
- Toxic Organic Wastes from compounds such as Chlorinated Hydrocarbons, Organophosphates and Carbamates.
- Toxic Inorganic Wastes such as Mercury, Nitrates and Nitrites, Salts, and Chlorine.
- Sediments resulting from timber cutting, agriculture, mining, and road construction.
- Thermal Pollution typically generated by power production facilities.

4 SEWAGE- TREATMENT AND SYSTEMS

Some basic environmental rules are:

- To divide different flows, technical and biological, and keep them separated.
- To stop the pollutions at the source is an often forgotten, but central part of all environmental work.

Sewage treatment is an important step of controlling our impact of polluting water. Depending of the type of water and pollutions we need different types of treatment and different methods.

Sanitary sewers transport wastewater from drains, toilets, sinks or appliance such as a clothes or dishwasher. This wastewater from residences and businesses flows to treatment plants where it is cleaned before being released, in this case into Lake Ontario.

Storm sewers capture rainwater or snowmelt from residential and commercial properties. This water flows into creeks, streams, rivers, channels, pipes or the lake. In the elder parts of the city of Toronto, most sewers are combined sewers.

A combined sewer carries both sanitary and storm drainage. During dry weather, combined sewers carry all contents to treatment plants. However, during wet weather, the volume of water may exceed the treatment plant's capacity and some of the water overflows untreated into the lake. The combined sewage system in Toronto, is very loaded. [2]

4.1 Storm water and storm water treatment

Surface runoff is a major factor in the character of the Great Lakes basin. [5], [9] Rain falling on exposed soil tilled for agriculture or cleared for construction accelerates erosion and the transport of soil particles and pollutants into tributaries. Suspended soil particles in water are deposited as sediment in the lakes and often collect near the mouths of tributaries and connecting channels. [1] Much of the sediment deposited in near shore areas is resuspended and carried farther into the lake during storms. The finest particles (clays and silts) may remain in suspension long enough to reach the mid-lake areas. Before settlement of the basin, streams typically ran clear year-round because natural vegetation prevented soil loss. Clearing of the original forest for agriculture and logging has resulted in both more erosion and runoff into the streams and lakes. This accelerated runoff aggravates flooding problems. [10]

4.2 Combined sewage overflow, CSO

When the Toronto sewers were constructed in the 19th century, and more or less up until the first half of the 20th century, one pipe carried both sanitary sewage from our bathrooms and kitchens, and water that ran off our roofs and roads. [10] With increased urbanization, the capacity of these sewers is greatly exceeded, causing Combined Sewer Overflow (CSO), when it rains. In Toronto and it's surrounding area there are about 30 combined sewers causing 50 to 60 overflows per year. [1], [10] The overflows may cause bad smell and the fecal coliform level goes up in the harbor and on Lake Ontario beaches. CSO is the root cause of beach closings in Toronto. [5]

A CSO is a very common way of controlling high flows in combined sewage systems. [1], [10] [13] The overflow is usually to a recipient or to another sewage pipe. When the sewage system is overloaded sewage is conducted out of the system without treatment. This is a very good way of eliminating problems in the combined sewage system. Problems like flooding in basements, apartments and at the treatment plants etc. The purpose with sewage overflows is to avoid [8]:

- Basement flooding
- Treatment plant over loading

Unfortunately this solution creates new problems, at the recipients. The new problems are for example [8]:

- Bad smell and a bad looking environment
- Intoxication, by poisonous metals and bacteria's
- Problems with increased oxygen demand, anoxic conditions and eutrophication.

5 NORTH TORONTO FACILITY

5.1 Toronto sewage system

In Toronto there are four major treatment plants in operation today, the Ashbridges Bay Treatment Plant is the biggest, the North Toronto Treatment Plant where our CSO is located, the Highland Creek Treatment Plant and the Humber Treatment Plant. These plants are owned and operated by Works and Emergency Services Water and Wastewater Services division, that is funded from money received as a surcharge on the water supplied to the community areas in Toronto and partly by industrial surcharge agreements. [2] 358 km of trunk collector sewers and eight pumping stations support the four treatment plants. [1]

The wastewater in Toronto is collected by an extensive underground sewer system. It flows by gravity down the slope of Toronto, and occasionally pumped, to a wastewater treatment plant where it undergoes treatment processes that remove solids, chemicals and other undesirables before the water is released into the natural water supply. [2], [10], [11] Toronto's four wastewater treatment plants operate under the guidelines set by the Ministry of Environment. Their removal effectiveness for suspended solids, biological oxygen demand and phosphorous ranges from 72 to 97 percent. [1]

5.1.1 North Toronto Treatment Plant

The CSO at the North Toronto Sewage Treatment Plant is one out of five greater CSO: s in the Toronto region. [2] When the CSO was built, it was meant to work as a storage basin. [2], [10] It should fill up during a rain event, to discharge the trunk sewer so that the sewage could be pumped back into the system again, when the event is over. [1], [10]

The North Toronto Treatment Plant is located just by the Don River near a very popular recreation area in Toronto. [10] The sewage system connected to the NTTP services an area of about 3060 ha, were the land use is approximately 78 % of public housing, 9 % of industrial/commercial activity's and about 13 % open of space. The systems incorporate about 15 km of trunk sewers with a diameter of 0.3 to 3.2 meters and have a capacity ranging between 1.5 to 50 m^3/s. The storage capacity of the NTTP is 6000 m^3 and the system overflows about 30 to 40 times a year. According to a modeling study, by Dr Jiri Marsalek, the system would overflow only once a year, if the storage volume were increased to 73 000 m^3. [1], [10]

5.1.2 Polymer/flow full-scale testing

A full scale testing was conducted at the North Toronto CSO storage tank and is described in "Field experience with chemically aided settling of combined sewers" [1]. The tank consists of a distribution channel and three cells, with three weirs with different elevations. When the storage tanks are full they will overflow to the Don River. When the event is over the water stored in the system is being pumped back in to the sewers.

The system was retrofitted with a coagulant dosage system, for pumping liquid polymeric coagulant and injection into the CSO in the four influent pipes, connecting the CSO influent channel and the distribution channel.

A control unit that determines the coagulant input for a certain CSO flow, estimated based on liquid levels operates the dosage system. The dosage of the system was such that small flows would receive no coagulant and large flows, > 6 m^3/s would be under dosed.

5.1.3 Results from the "Polymer/flow full-scale testing"

The full-scale test indicated that coagulant aided settling of CSO could meet the provincial CSO treatment objective for TSS, Total Suspended Solids, and the achievement of the required BOD_5 removal. Thou good performance of the polymer coagulation treatment system depends on the correct polymer dosage.

To reduce operating costs and to avoid problems with coagulant overdosing a variable dosage rate, that reflect variations in TSS concentration in the CSO would be required. For TSS concentrations below the policy limit of Ontario, no coagulant is required, but increase proportionally for higher TSS concentrations. It's a fact that a good measurement of the TSS concentration and good performance of the dosage system is central for good results in the coagulation treatment system.

Requirements for good performance of the system, according to the "Field experience with chemically aided settling of combined sewers" [1]:

- Good performance of the dosing system
- System reliability
- Precision of coagulant dispensing
- Good mixing of the wastewater
- Good measurements of TSS
- Good measurements of flows

A polymeric coagulant like this particularly one might be toxic to gathead minnows and some clabocerean species, even at concentrations as low as 1-7 mg per liter, depending on effluent quality and the concentration of suspended solids. In this specific case, preliminary laboratory testing did not find any toxicity at concentrations as high as 16 mg/l. But changing in TSS together with improper dosing of coagulant may result in toxicity. (The possibility of increasing CSO toxicity by polymer addition at the study site was noted earlier by Marsalek et al, 1999 and confirmed later at field experiments in September 10, 2000.) The results show that high dosage of coagulant produced good removals of TSS, BOD, COD and total phosphorus, but toxic to Rainbow trout and Daphnia magna bioassays in spite of a non toxic influent. This points to the need to prevent coagulant overdosing. [1]

5.2 Problem with the construction

When the CSO in North Toronto once was built it was originally meant to be a storage basin that discharges the combined sewers in north Toronto. [2] When a rain event occurs, the trunk overflow to a storage basin and when it stops raining, the CSO could be pumped back into the system again. [1] The system was quite soon to small to work as a storage basin. [2] Instead of working as a storage basin it just works like a normal CSO. During the years the system has been more and more loaded, and today it's overflowing almost every time it rains. [1] Well that might not seem to be a big problem, it was built as a storage basin and now it works like a CSO.

This project is supposed to determine the flows, mixing and settling of the water in the North Toronto CSO storage system, so that one can predict the needed quantity of polymer for a fixed level of pollution. Next step in the project is to construct a measuring instrument for the pollutions. In that way one could dose the most sufficient amount of polymer for every storm event. If to much polymer is added it can act toxic in nature, and the CSO will be to pollute for the Don River, if to less is added. [1]

5.3 Solving the problem of the construction

The hydraulic for these systems is usually quite easy to solve, as long as the water not is polluted and you have good finances. Unfortunately, in today's urbanized society, we know that most water is polluted or may cause damage to a recipient.

One way to solve the problem with combined sewers once for all would be to build new separated systems. The combined sewers are usually located in bigger cities in really complex systems, and money would be the key for this solution. But unfortunately we know the fact about, or lack of, money much to well. Therefore we need a system that is cheap and easy to adapt into the existing system.

This could for example be a system that discharges the combined sewage overflow directly before it reaches the recipient's. Inn this case we already have a system like this at the North Toronto treatment plant, thou it's not working properly. The problem is that the system gets overloaded during storm events. Here again, the best way to solve this problem, would likely be to build a new system or totally rebuilt the existing one, but one of the most economical solutions might be to speed up the process in the system or increase the capacity. This could be done either by increasing the volume of the system or by adding a chemical that speed up the settling process in the system and there by increases the capacity of the system. The second solution is probably is the easiest one and the most interesting.

In our case the chemical is a polymer. This polymer works like glue, that sticks to particles in the CSO and makes particles stick to other particles so they get bigger, heavier and then sink to the bottom, almost like a flocculation process. The polymer is not toxic in it self, thou it might act as a biological toxic in nature. If to much polymer is added to the CSO, so that all of it does not "react", it might reach the Don River. If to much polymer reach the River, it can get caught in to gills on fishes and other biological, then particles will get stuck in the polymer so that the fish will suffocate. There for you can say that the polymer can act toxic in nature.

As in other parts of the world, combined sewer overflows, is a problem within the great lakes ecosystem. "The International Joint Commission" made an approach to this problem, and designated 40 "Areas of concern", in the Great Lakes Basin, whit remedial action plans to improve persistent water quality. Of seventeen "Areas of concern" in Canada, 10 were contaminated by CSO: s, two of them is The Toronto Waterfront and The Hamilton harbor. [12]

There are a number of different methods to solve the problems with CSO: s, as separation of storm and sanity sewers, increase the storage of wet weather flow, create storage basins and increasing or building of new treatment plants. However, some of these options are way to expensive. Therefore satellite treatment may be a good, more economic, solution. [13] The satellite treatment system in the North Toronto is a cationic coagulant that is supposed to variant with the flow and amount of pollution. [10]

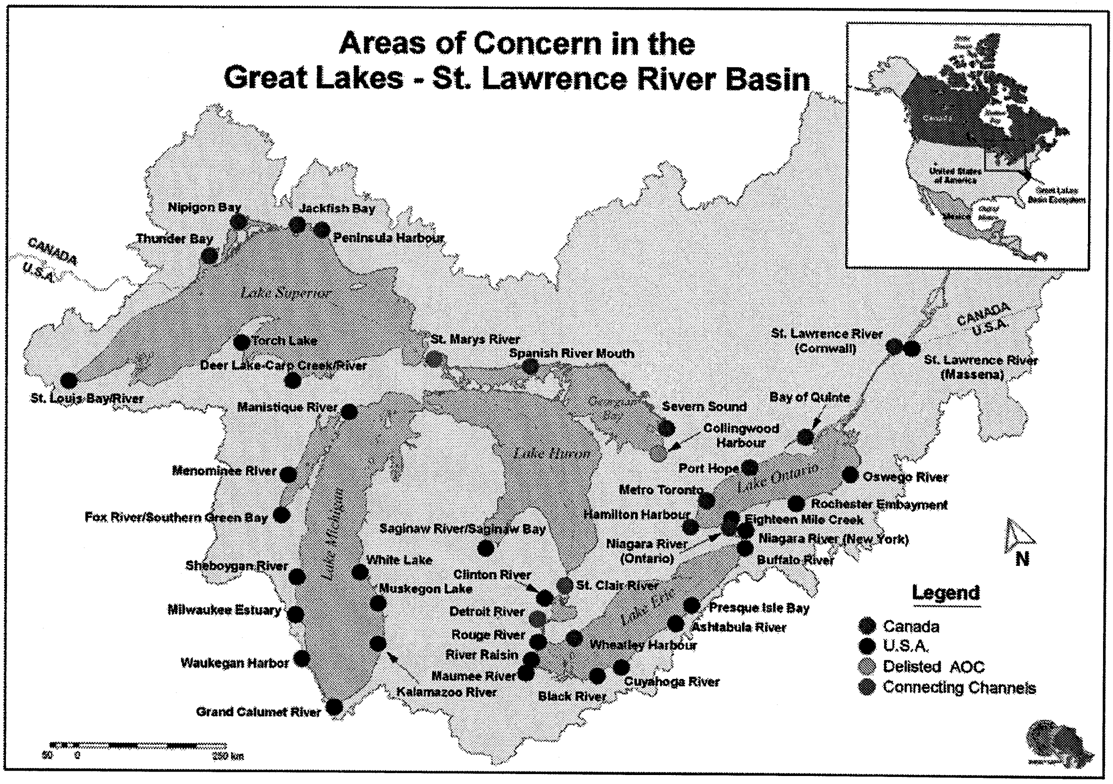


Fig. 5.3.1. Areas of concern in the Great Lakes. (Environment Canada, 1999. URL: http://www.on.ec.gc.ca/glimr/maps-e.html , 2002-03-04)

5.4 The structure of the North Toronto CSO

The structure of the North Toronto CSO is rather complex and reconstructed through the years. The oldest part is the Storm water tank, meanwhile the three CSO tanks are constructed later.

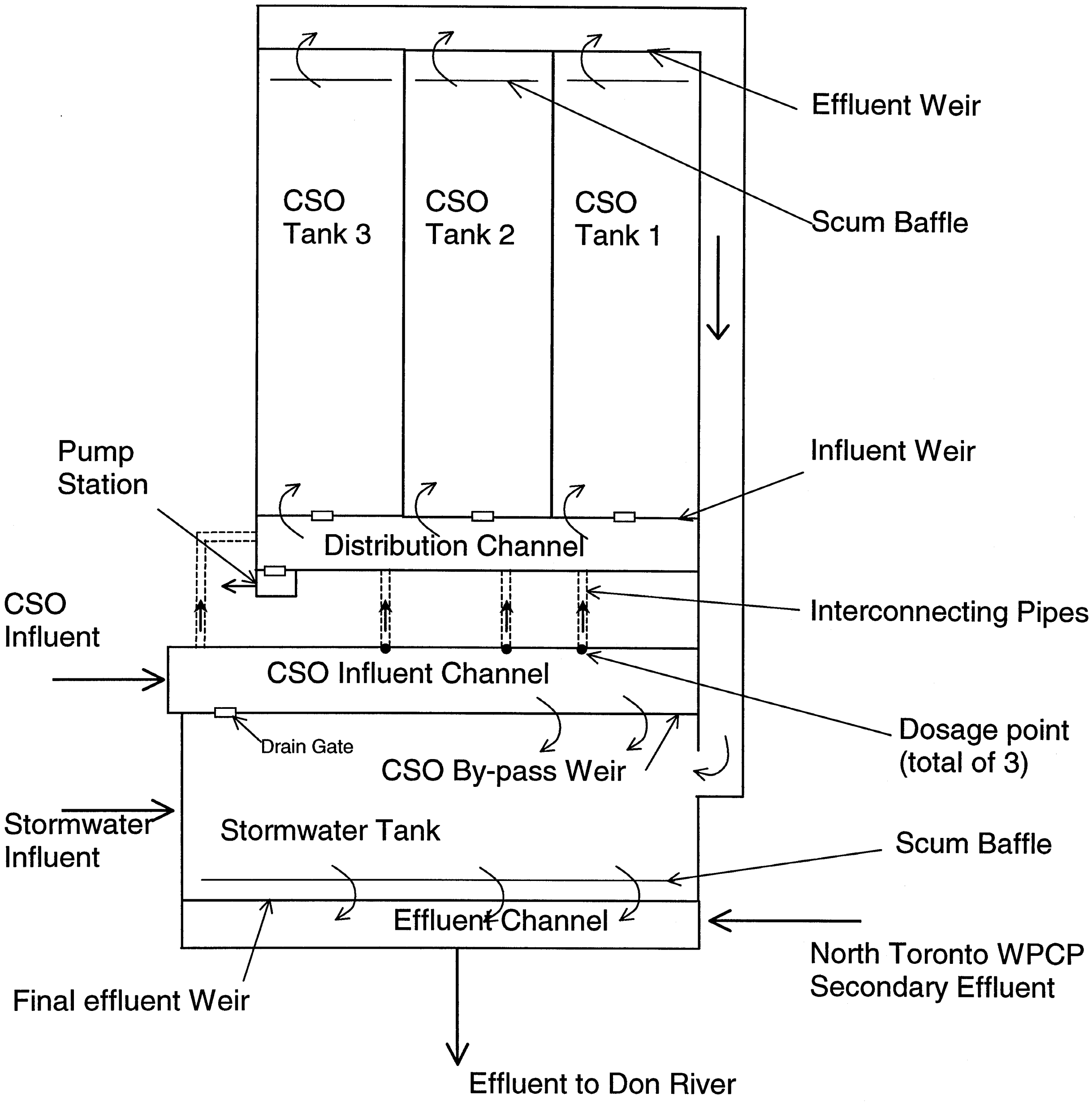


Fig. 5.4.1. Sketch of the north Toronto CSO. (Ola Lagerkvist)

During an event, CSO flows into the inlet channel from the adjacent combined sewers. Then the water flows throw the pipes in to the mixing channel.

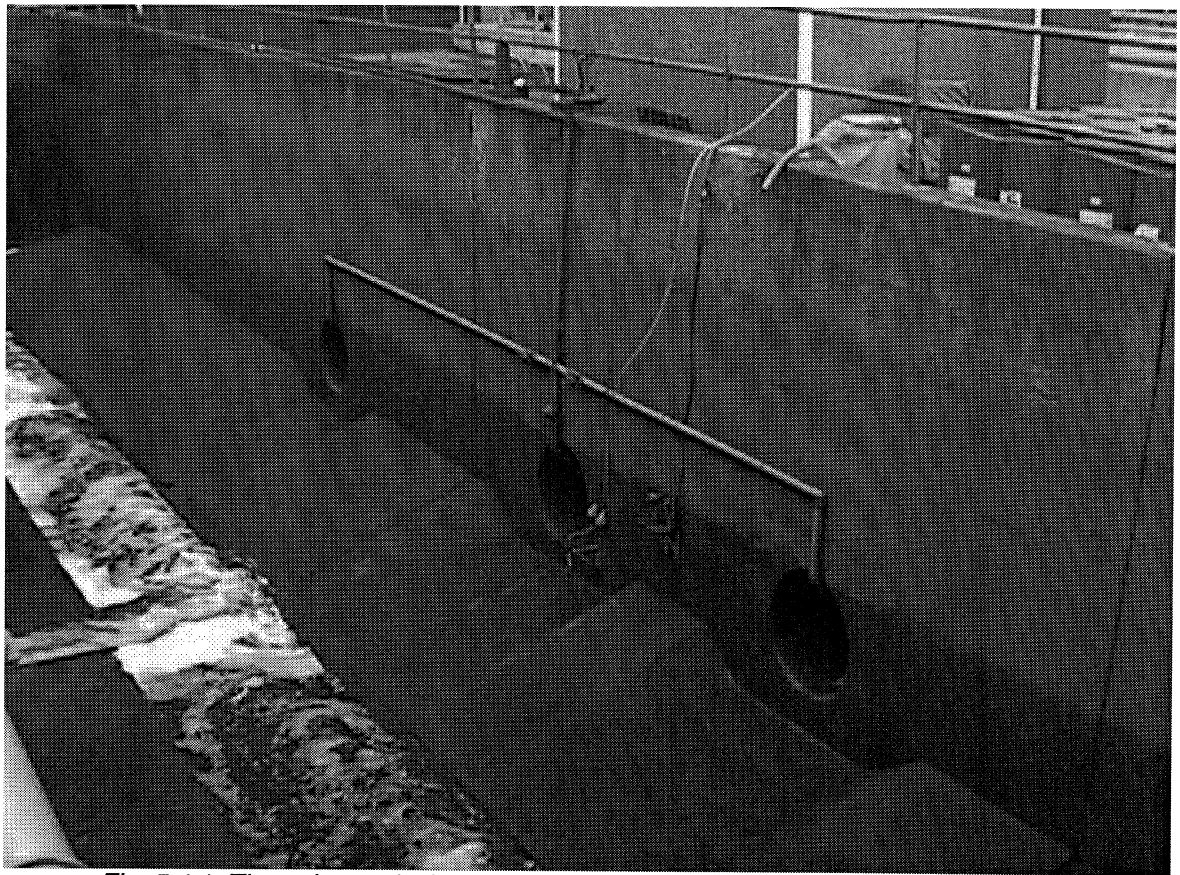


Fig. 5.4.1. The polymer dosing system can be seen at the mix pipe inlets in the CSO influent channel. (Photo by Quintin Rochford)

The polymer is added to the CSO in the first part of the pipes and is supposed to mix with the water in the mixing channel. After the mix channel the water flows into the three CSO storage tanks.

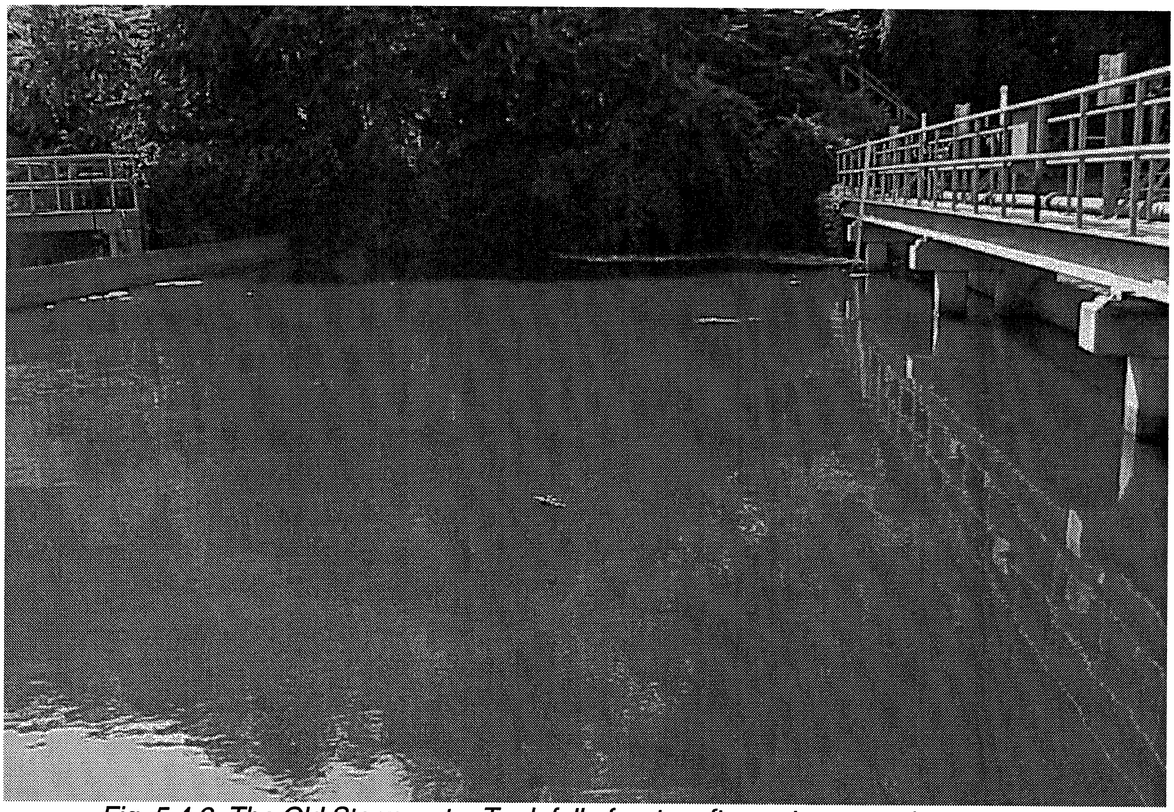


Fig. 5.4.2. The Old Storm water Tank full of water after a storm event (Photo by Quintin Rochford)

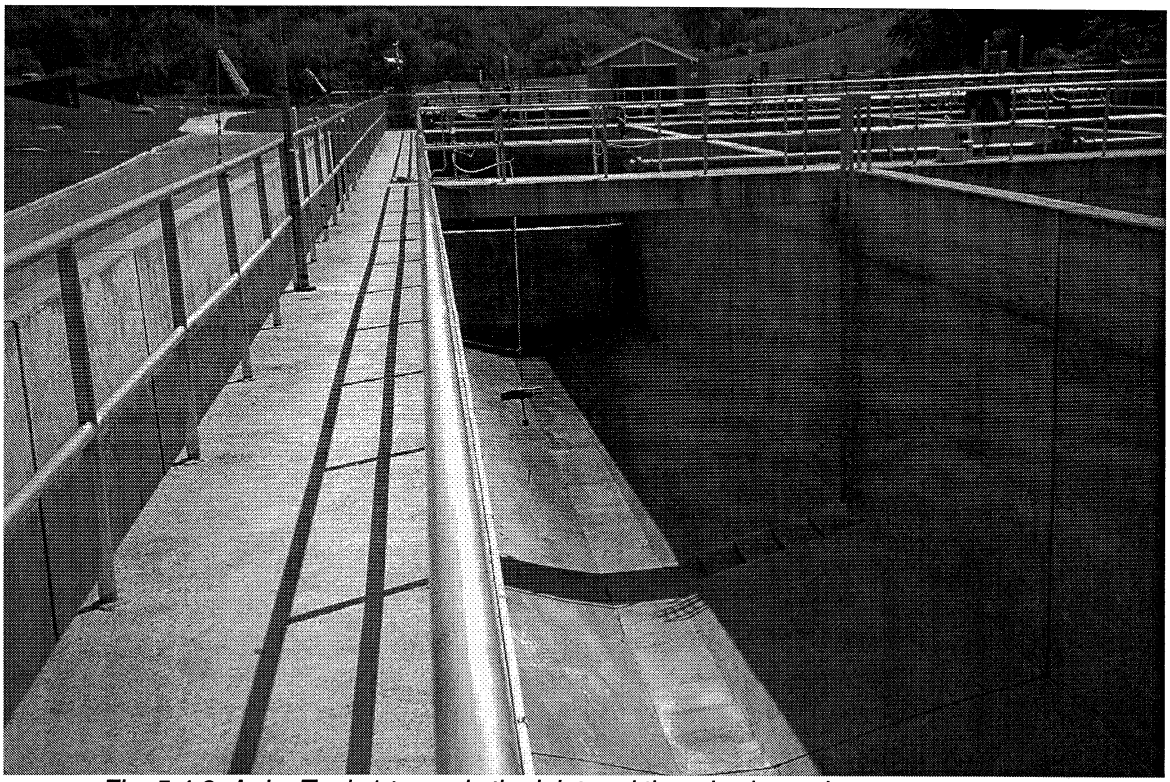


Fig. 5.4.3. A dry Tank 1 towards the inlet and the mix channel. (Photo by Quintin Rochford)

When the CSO tanks is filled up they overflow into a channel that will transport the CSO in to a storm water tank, where the CSO mixes with storm sewer.

Fig. 5.4.3. Dry Tank 1 towards inlet. (Photo by Quintin Rochford)

When the storm water tank is full the water will overflow and blend with the effluent from the WPCP before it reach the Don River.

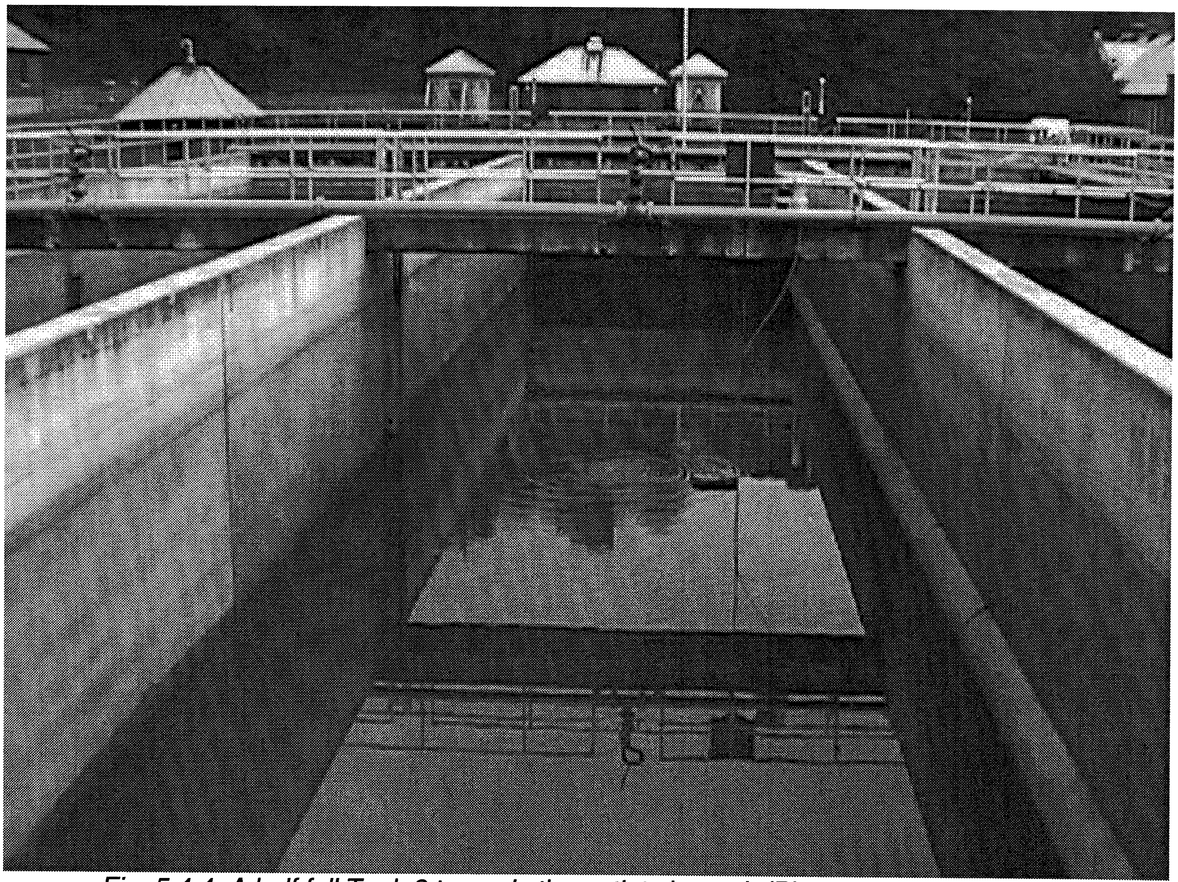


Fig. 5.4.4. A half full Tank 2 towards the outlet channel. (Photo by Quintin Rochford)

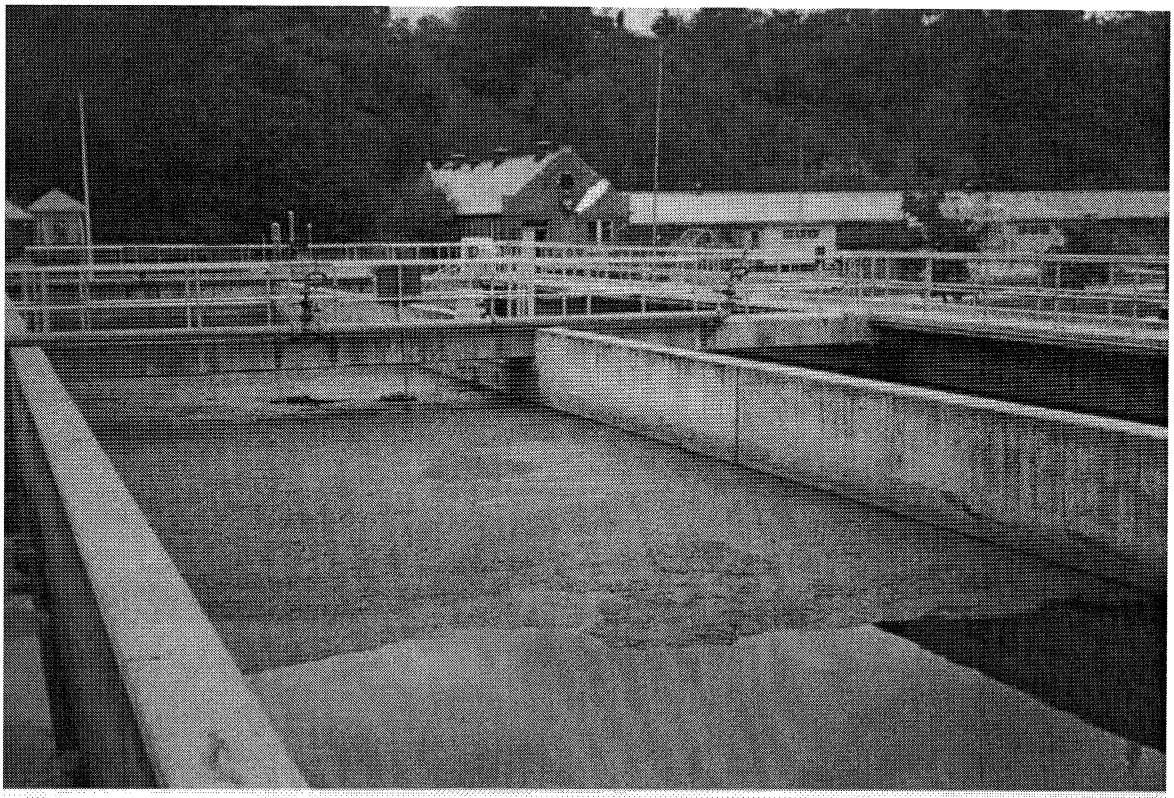


Fig. 5.4.5. A full Tank 2 towards the outlet channel. (Photo by Quintin Rochford)

Fig. 5.4.6.The Storm water tank outlet weir. (Photo by Quintin Rochford)

6 COMPUTATIONAL FLUID DYNAMICS

In complex geometries is it often hard to determine flows analytical. One has to make models and experiments to estimate the flow. The development of CFD (Computational fluid dynamics) has made it easier to calculate and analyze complicated flows. There are several unique advantages of CFD over experiment-based approaches to fluid systems design, e.g. substantial reduction of lead times and costs of new design, ability to study systems where controlled experiments are difficult or impossible to perform, ability to study systems under hazardous conditions at and beyond their normal performance limits.

This section of the report, will give you a brief introduction to CFD and what is implemented in a CFD code. [14]

6.1 CFD codes

All commercial CFD packages include sophisticated user interfaces to input problem parameters and to examine the results. There are three main elements in a CFD code, a pre-processor, a solver and a post-processor. These elements will briefly be examined. ([14] H K Versteeg et al (1995))

6.1.1 Pre-processor

At the pre-processing stage there is a number of activities that has to be made [14]:

- Definition of the geometry of the region of interest.
- Grid generation: sub-division of the domain into a number of smaller, non-overlapping sub-domains.
- Selection of the physical and chemical phenomena that need to be modeled.
- Definition of fluid properties.
- Specification of appropriate boundary conditions at cells, which coincide with or touch the domain boundary.

6.1.2 Solver

There are three techniques that can be used to get a numerical solution: finite difference, finite element and spectral methods. In these techniques an approximation is made of the unknown flow variables by means of simple functions. Discretisation is made by substitution of the approximations into the governing flow equations and subsequent mathematical manipulations. Thereafter the algebraic equations can be solved. The most well established technique is the finite volume method, which is formulated as a special finite difference method. The numerical algorithm consists of following steps:

- Formal integration of the governing equations of fluid flow over all the (finite) control volumes of the solution domain.
- Discretisation involves the substitution of a variety of finite-difference-type approximations for the terms in the integrated equation representing flow process such as convection, diffusion and sources. This converts the integral equations into a system of algebraic equations.
- Solution of the algebraic equations by an iterative method.

The first step, the control volume integration, distinguishes the finite volume method from all other CFD techniques. [14]

6.1.3 Post-processor

The post-processor is a tool to work up and make a visualization of the results. In CFD packages includes these versatile data visualization tools [14]:

- Domain geometry and grid display.
- Vector plots.
- Line and shaded contour plots.
- 2D and 3D surface plots
- Particle tracking
- View manipulation (translation, rotation, scaling etc.).
- Color postscript output.
- Animation for dynamic result display.

6.2 Mathematical models

Many physical problems can be described with mathematical models. The problems are often described with partial differential equations (PDE) e.g. heat transfer and fluid dynamics. The equations are built on conservation laws, Newton's second law and first law of thermodynamics.
According to the conservation laws in fluid dynamics, the mass flow is constant, will simplify complex processes that are difficult or impossible to solve with mathematical expressions. There are three mathematical statements of the conservation laws of physics that is represented for fluid flow [14]:

- The mass of a fluid is conserved.
- The rate change of momentum equals the sum of the forces on a fluid particle (Newton's second law).
- The rate of change of energy is equal to the sum of the rate of heat addition to and the rate of work done on a fluid particle (first law of thermodynamics).

6.2.1 Mass conservation

The net rate of flow of mass into an element is equal to the rate of increase of mass in fluid element. The mass flow can be determined as a product of density, area and velocity perpendicular to the surface. These statements are used to derive the mass conservation equation. For an incompressible fluid the density ρ is constant and the following continuity equation can be derived:

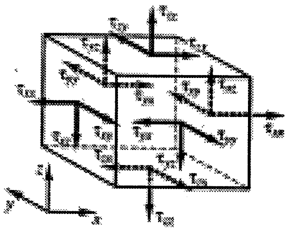
$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

u represents the velocity in x-direction, v the velocity in y-direction and w in z-direction. [14]

6.2.2 Momentum equation

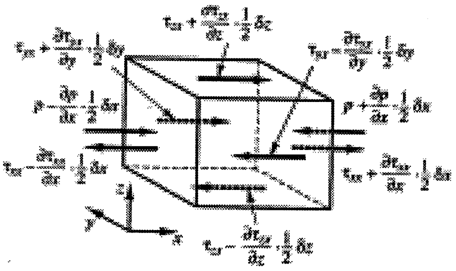
The sum of forces on a fluid particle is equal to the rate of increase of momentum of fluid particle (Newton's second law). The momentum in an isolated system is constant and a change of a systems momentum is only depended on of external forces.

The state of stress of a fluid element is defined in terms of pressure and viscous stresses. The pressure, a normal stress, is denoted by *p*. Viscous stresses are denoted by τ. The usual suffix notation τ_{ij} is applied to indicate the direction of the viscous stresses. The suffices *i* and *j* in τ_{ij} indicate that the stress component acts in the *j*-direction on a surface normal to the *i*-direction.



First we consider the x-components of components τ_{zx}, τ_{xx} and τ_{yx} shown in Figure

The magnitude of a force resulting from a surface stress is the product of stress and area. Forces aligned with the direction of a co-ordinate axis get a positive sign and those in the opposite direction a negative sign. The net force in the x,y,z-direction is the sum of the force components acting in that direction on the fluid element.



The x,y,z-component of the momentum equation is found by setting the rate of change of x,y,z-momentum of the fluid particle equal to the total force in the x,y,z-direction. One get:

$$\rho\frac{Du}{Dt} = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} \qquad \textbf{eq 1}$$

$$\rho\frac{Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} \qquad \textbf{eq 2}$$

$$\rho\frac{Dz}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} \qquad \textbf{eq 3}$$

[14]

6.2.3 Navier-Stokes equations for a Newtonian fluid

Navier-Stokes equations are three partial differential equations, which can be derived from the statements of conservation of mass and momentum in a viscous fluid. The viscosity for a Newtonian, incompressible fluid can be expressed by a dynamic viscosity constant μ, which describes the relationship between inner friction and linear deformations. With equation 2, 3 and 4 together with equation 1, one get:

$$\frac{Du}{Dt}=\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \qquad \textbf{eq 4}$$

$$\frac{Dv}{Dt}=\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \qquad \textbf{eq 5}$$

$$\frac{Dw}{Dt}=\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \qquad \textbf{eq 6}$$

[14]

6.2.4 Turbulence

A form of fluid flow in which particles of the fluid move with irregular local velocities and pressures

Turbulence flow is a type of fluid (gas or liquid) flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction. [15]

Turbulent flows cannot be evaluated solely from computed predictions and depend on a mixture of experimental data and mathematical models for their analysis, with much of modern fluid-mechanics research still being devoted to better formulations of turbulence. The transitional nature from laminar to turbulent flows and the complexity of the turbulent flow can be observed as cigarette smoke rises into very still air. At first it rises in a laminar streamline motion but after some distance it becomes unstable and breaks up into an intertwining eddy pattern. [16]

The random nature of a turbulent flow precludes computations based on a complete description of the motion of all the fluid particles. In order to simulate the eddies that are smaller than the smallest element in the modeling domain, the Navier-Stokes equation can be rewritten by decomposing the velocities and the pressures into a steady mean value *U* respectively *P* with fluctuating components *u'(t)* respectively *p'(t)* superimposed on it, one get:

$$U_i = \overline{U} + u'(t)$$
$$P_i = \overline{P} + p'(t)$$

eq 7a-b

where

U_i, P_i = velocity respectively pressure in *i*-direction
$\overline{U}$, $\overline{P}$ = average velocity respectively average pressure
u'(t), p'(t) = velocity- respectively pressure fluctuations

Inserting the equations 8 a-b into Navier-Stokes equations (equation. 5-7) one get:

$$\frac{\partial U_j}{\partial x_j} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\frac{\mu}{\rho}\frac{\partial U_i}{\partial x_i} - \overline{u_i u_j}\right]$$

eq 8

The term $\overline{u_i u_j}$ contains the Reynolds stresses [14]

6.2.5 The k-ε model

The k-ε model is the most used turbulence model. The model considers turbulence, diffusion and production respectively destruction of turbulence. Two transportation equations has to be solved, one for the kinetic energy *k* and one for dissipation velocity ε for the kinetic energy.

$$\rho\frac{Dk}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right]-\rho\overline{u_i{}'u_j{}'}\frac{\partial u_i}{\partial x_i}-\rho\varepsilon \tag{eq 9}$$

(I) (II) (III) (IV)

$$\rho\frac{D\varepsilon}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right]-C_{1\varepsilon}\frac{\varepsilon}{k}\left(\rho\overline{u_i{}'u_j{}'}\frac{\partial u_i}{\partial x_i}\right)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{eq 10}$$

(I) (II) (III) (IV)

k = average kinetic energy
μ= viscosity constant
σ_k, σ_ε = Prandtl number
$C1\varepsilon$, $C2\varepsilon$ = constants
$\mu_t = C\rho\ell\vartheta$ = eddy viscosity

C dimensionless constant
ℓ represent a length scale (m)
ϑ represent a velocity scale (m/s)

In words the equations are:

(I) Rate of change and transport of *k* or ε by convection
(II) Transport of *k* or ε by diffusion
(III) Rate of production of *k* or ε
(IV) Rate of destruction of *k* or ε

[14]

7 METHOD

7.1 Geometry

The modelling geometry consists of the three tanks, the distribution channel, the upper part of the CSO-effluent and the four interconnecting pipes. Tank 3 and tank 2 are 42.1m long, 7.3m wide and they slopes with 4.5%. Tank 1 is equal to the two other tanks but is 7m wide. The distribution channel is 2m wide and 22.4m long and it slopes with 2.5 %. Pipe 1, 2 and 3 has a diameter of 0.9m and are 10m long an they slopes with 9%. Pipe 4 is set to 1m. This because of it's structure with manholes, which would make the modelling very hard to do. He CSO effluent is 2m wide and it slopes with 1.9%.

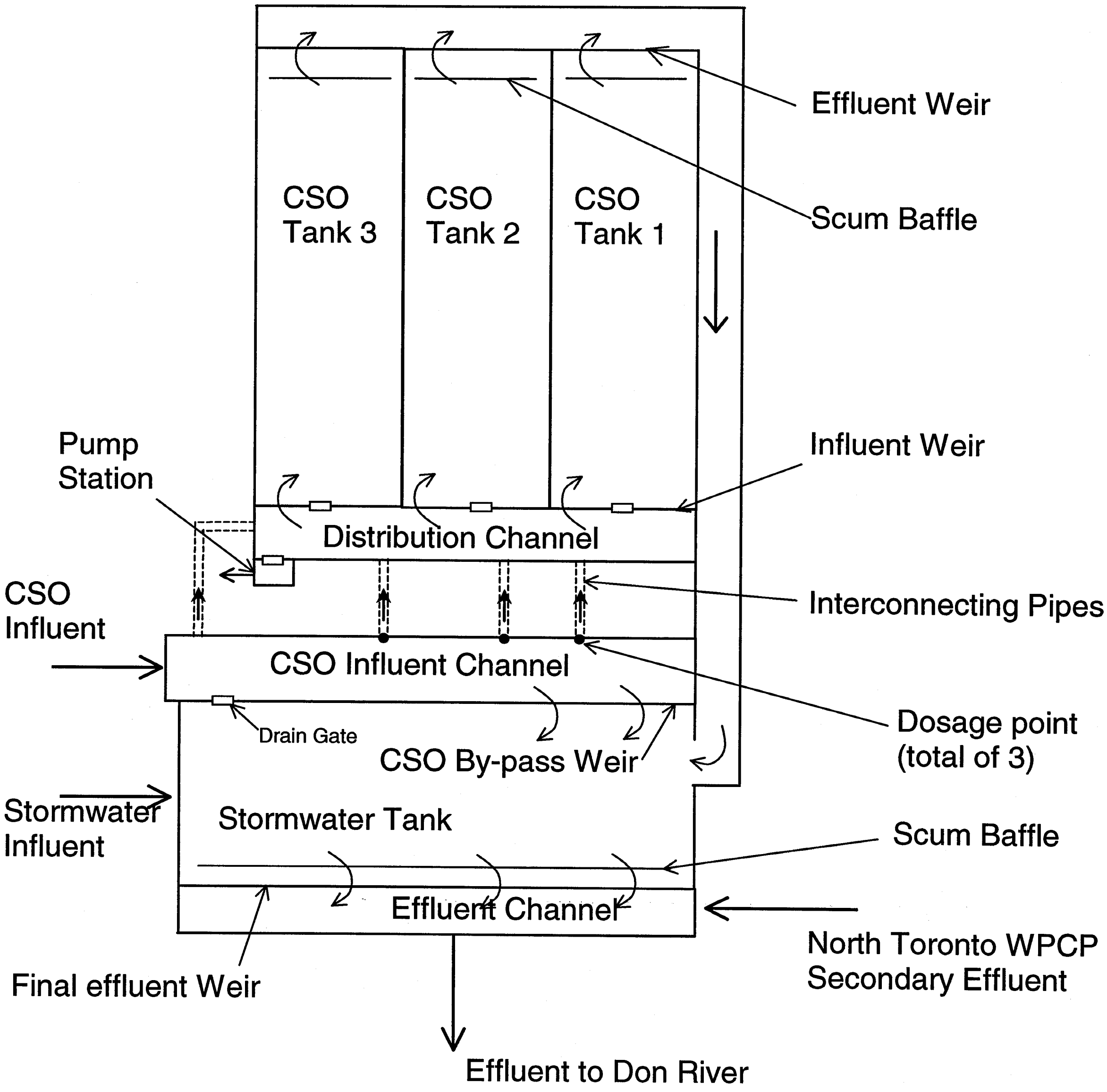


Fig 7.1.1. Plan sketch of the North Toronto CSO. Ola Lagerkvist.

7.2 Gambit

The geometry and the mesh are made in a preprocessor named Gambit. In Gambit you define your modeling domain and the boundary conditions. The geometry is created by first create vertices, lines between the vertices, faces of the connecting lines and volumes of the connecting faces. The measurements in the geometry are taken from blueprints and by complemented measures on site. All the work with the geometry and the mesh is written in journal files. The journal files makes it easier to redefine the model if it's needed.

7.2.1 Mesh

The mesh is made by hexahedral elements. The domain consists of 214122 elements. The skew ness of the elements is ranged between 0-1. 0 marks a very good element and 1 a very bad element. 70 % of the elements are ranging between 0-0,1. The worst elements have a skew ness of 0,63 but it is only 22. This tells us that we have a rather good mesh. The mesh is shown in the pictures below.

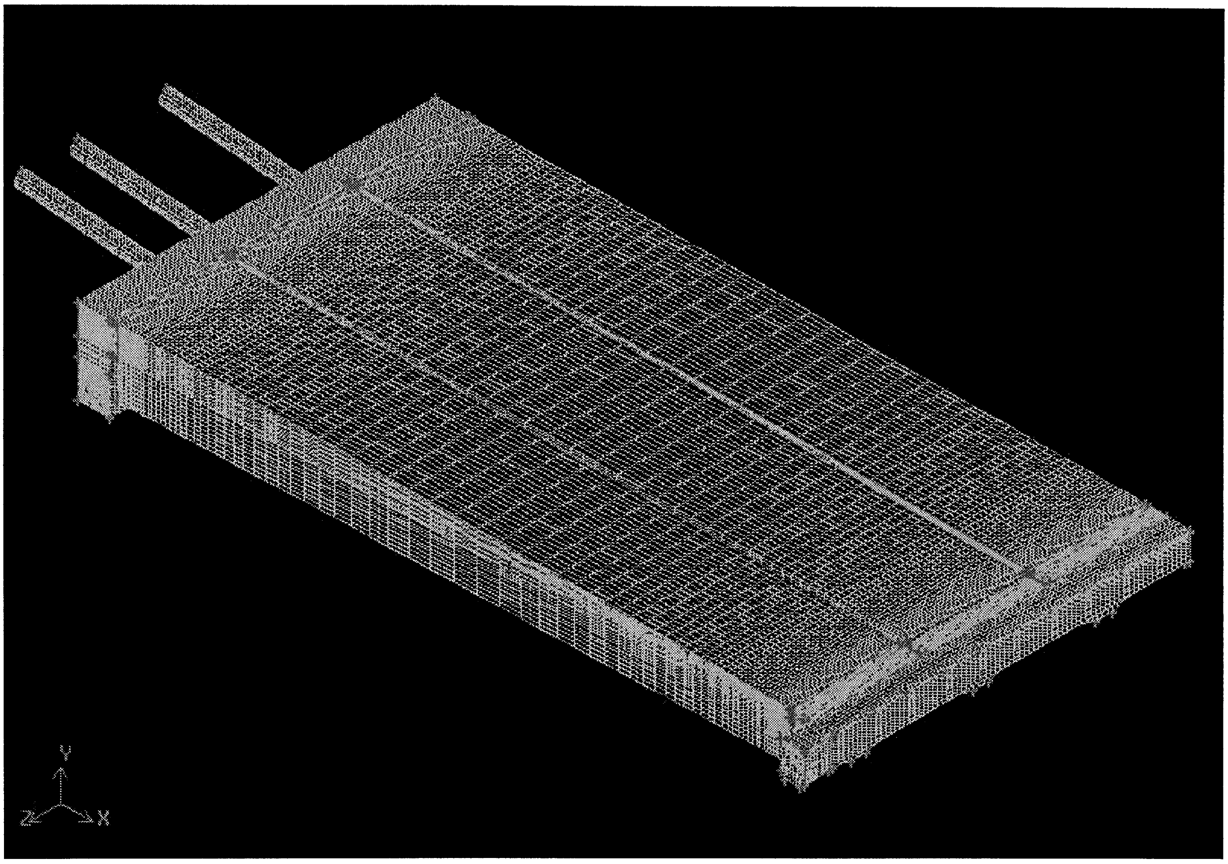


Fig. 7.2.1.1. The mesh in Gambit.

7.3 Calculations

The flow calculations and the particle track are made in Fluent 5.0. Fluent is a finite volume program. It solves the Navier-Stokes equations numerically for a Newtonian fluid. Once the geometry and the mesh are made in Gambit, the gambit file is imported into Fluent. In fluent you define all the material properties, set the solution controls and define the velocity components at the inlets.

The density for water is set to 998,2 kg/m^3 and the viscosity to 0,001003 kg/ms.

We have done several calculations. The most interesting ones will be presented in this report. From the beginning we tried to model just the mixing channel but it showed to be very difficult to get descent results. It was very hard to set the boundary conditions on the three outlets and we got very different results depending on which condition that were set. Therefore we decided to include the three tanks and the outlet in the model to make appropriate conditions.

The calculations that will be presented in this report are four steady state calculations with three different flows. The flows are 2, 4 and 6 m^3/s. In the case with 6 m^3/s we have done one calculation where the equations are solved by the first order modeling scheme and one by the second order scheme.

The convergence criterion for the residuals is set to 10^{-6} in the first order scheme and to 10^{-4} in the second order scheme. [14]

7.4 Error, sources and assumptions

The boundary conditions at the inlets are set equal for the four pipes, because we don't know the velocity magnitude for the pipes. An even distributed flow in the pipes can differ from reality, but the pipes have similar friction so we think this assumption is close to the truth.

The domain is divided in finite volumes. The result can depend on the distortion of the elements. Big distortion can give lousy results and big errors. It's important to make the mesh finer where you expect there is large turbulence. In areas where the gradients are big it's also essential to have small elements. In Fluent you cannot model turbulence and eddies in an element.

The modeling is made by the first order scheme and the second order scheme. The first order scheme gives very low residuals but the diffusion values are overestimated. The second order scheme gives much higher residuals and in our case a non-significant mass balance. [14]

8 PARTICLE TRACKING

To find out about the tanks hydraulic function, we have also been simulating a particle tracking in Fluent. A concentration of 100 kg/m^3 is added in all four pipes for two seconds, as a pulse load. Thereafter the concentrations will be measured in the inlets and outlets of all tanks and plotted in a graph. The time that it takes for the pulse to go through a tank will give us an estimation of particles mean delay time in the specific tank. Together with our examinations of velocities in the system the particle tracking will give us a good idea of how the system works.

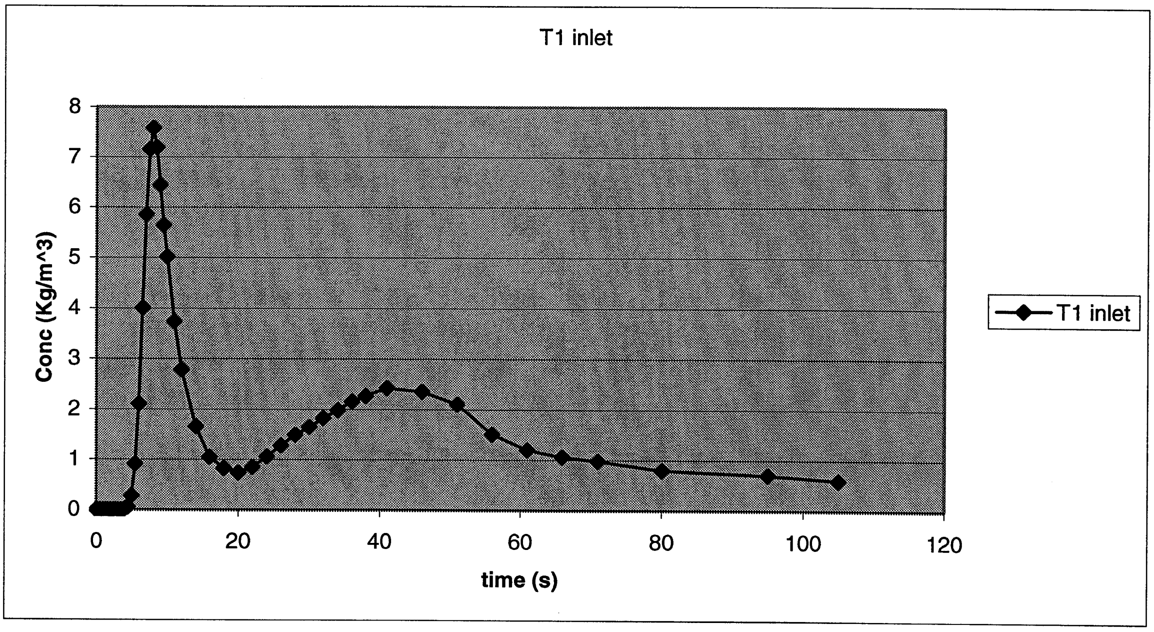


Fig. 8.1 Concentration measured at the inlet of Tank 1

The graph of concentration for inlet to tank one, plotted against time, shows that the pulse from pipe 1, 2 and 3 will reach the tanks first and that the pulse from pipe 4 will be slower and more spread out.

We can observe a similar curve from both tank 2:

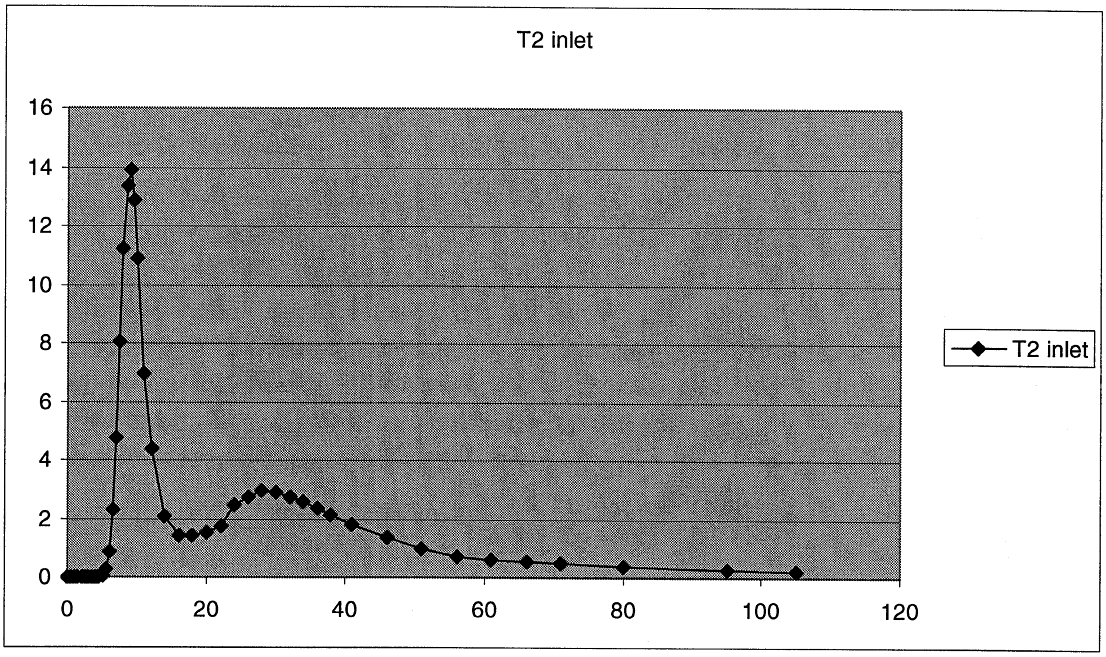


Fig. 8.2 Concentration measured at the inlet of Tank 2

and tank 3:

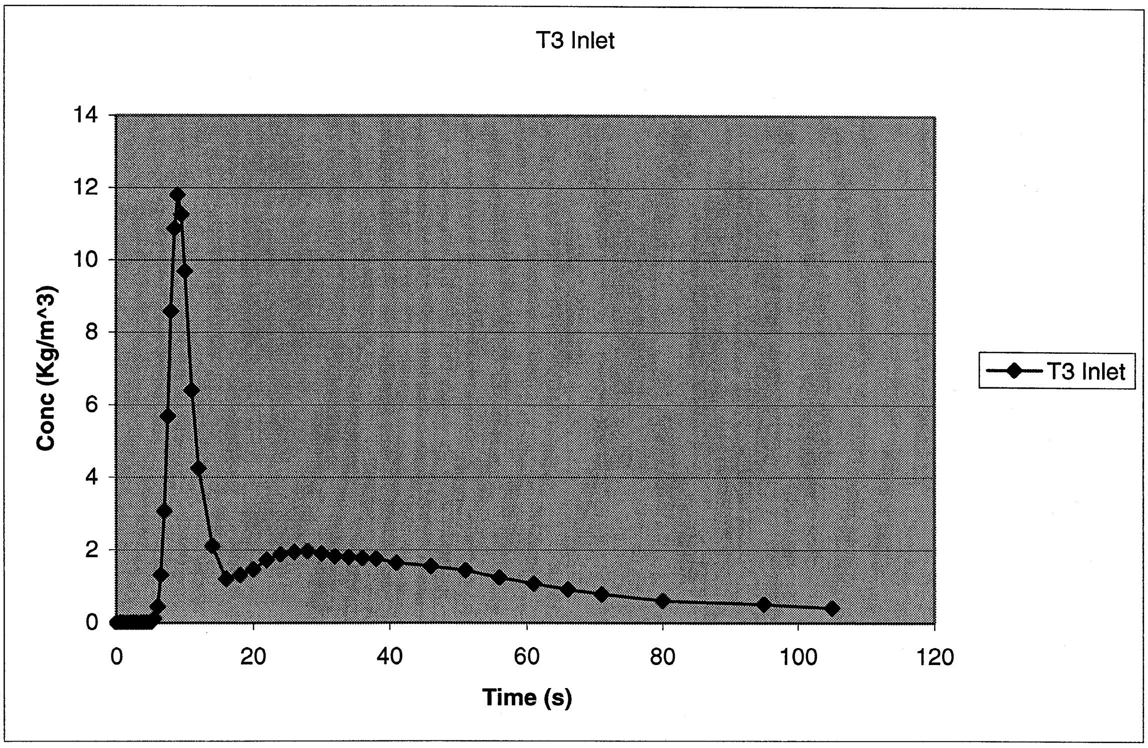


Fig. 8.3 Concentration measured at the inlet of Tank 3

The first pulse is so fast because the three pipes are located so close to the three tank inlets. The jet from the pipes cuts through the mix channel, hits the wall against the tanks and a stream goes up to the surface and in to tank three and two. The jet to tank one hits more straight in to the tank than the jet to tank two and three.

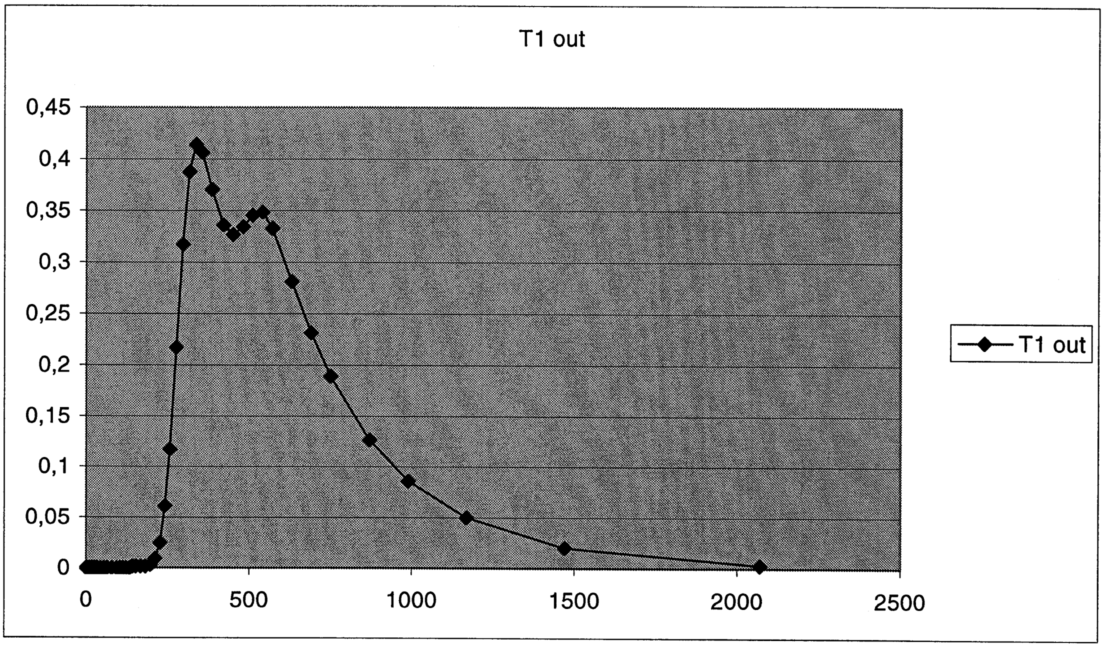


Fig. 8.4 Concentration measured at the outlet of Tank 1

The graph of the outlet of tank one sows that the concentration has been smothered out in time, but one can still see both pulses. The main look of the graphs is the same for all of the tanks, but they differ a little in time and stretch.

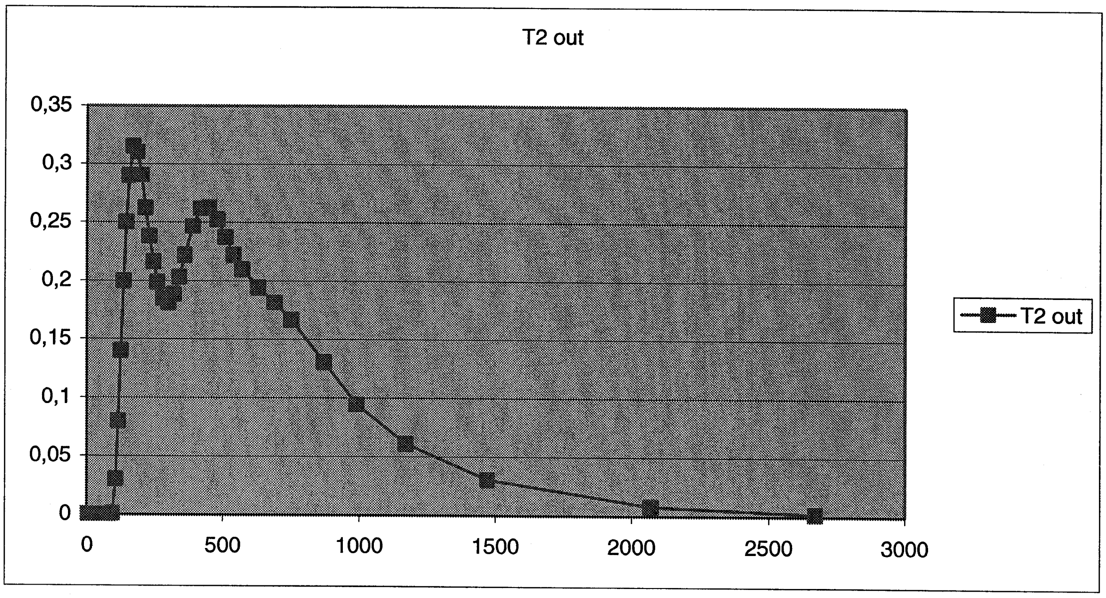


Fig. 8.5 Concentration measured at the outlet of Tank 3

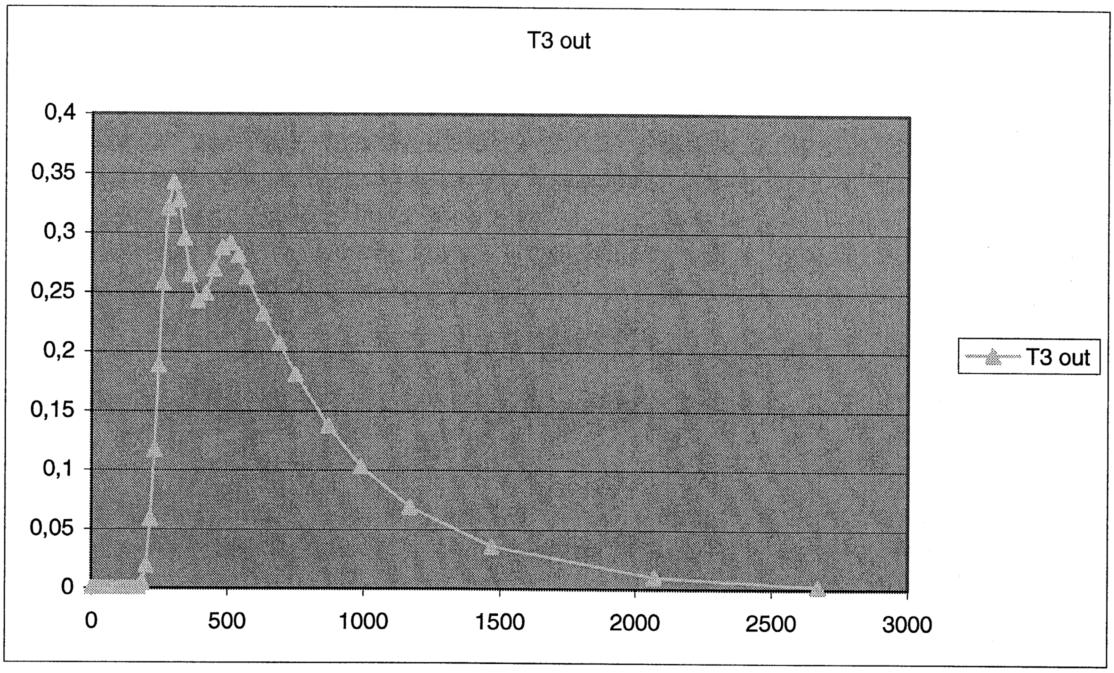


Fig. 8.6 Concentration measured at the outlet of Tank 3

The estimation of mean mass fraction in the graphs has been calculated in excel, and can be seen in appendix 1.

To get an estimation of the tanks hydraulic function we compared the theoretical mean delay time with the in Fluent calculated mean delay time for the three tanks, and the mix channel. The results are presented below and the calculations are attached in appendix 2

$$t = \textit{Approximated percentage of tank use} = \frac{T_{calc}}{T_{nom}}$$

$$T_{nom} = \textit{Nominal delay time} = \frac{V_{Tank}}{Q_{Tank}}$$

$$T_{calc} = \textit{Calculated delay time}$$

$$T_{nom1} = 575\ s \qquad T_{cent1} = 496\ s \qquad t_1 = \frac{496}{575} = 0.86$$

$$T_{nom2} = 635\ s \qquad T_{cent2} = 499\ s \qquad t_2 = \frac{499}{635} = 0.78$$

$$T_{nom3} = 676\ s \qquad T_{cent3} = 540\ s \qquad t_3 = \frac{540}{676} = 0.80$$

The particle track shows that the tanks volumes are well used, with a good plug flow. From the pictures in appendix 3 it shows that the jet cuts right in to tank one, and hits the wall in tank two and three, before the stream reach the surface. The mixing in the mix channel is fairly good, though an ordinary mixing system would be to prefer for mixing the polymer. [7]

9 RESULTS AND DISCUSION

All calculations converged, with satisfaction, appendix 4. Generally the flow pattern in the mix channel and the three tanks is dominated of the jet effect created from the mix pipes. Most water flows through tank one, probably because of its bigger opening and that the jet stream from “mix pipe one” hits through the opening.

- 36 % of the flow flows through tank 1
- 33 % of the flow flows through tank 2
- 31 % of the flow flows through tank 3

The flow in the mix pipes is relatively stable in our simulations, and the mixing in the pipes is not important for the total mix. Here we have to make a reservation on that we did not simulate the polymer dosing system.

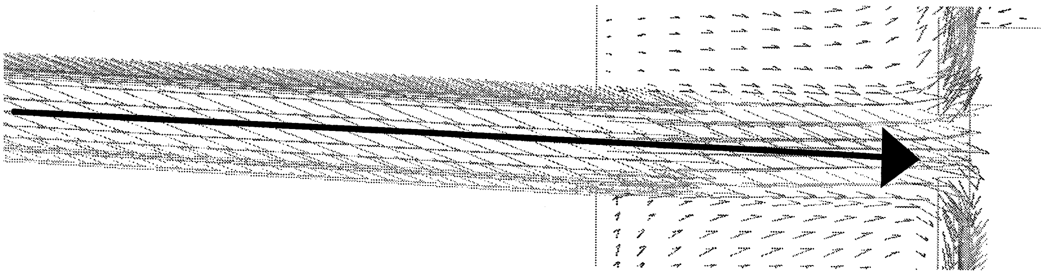


Fig. 9.1 Not much mixing in the pipes

The mixing in the mix channel is fairly good, even though some streams goes to straight in to the tanks.

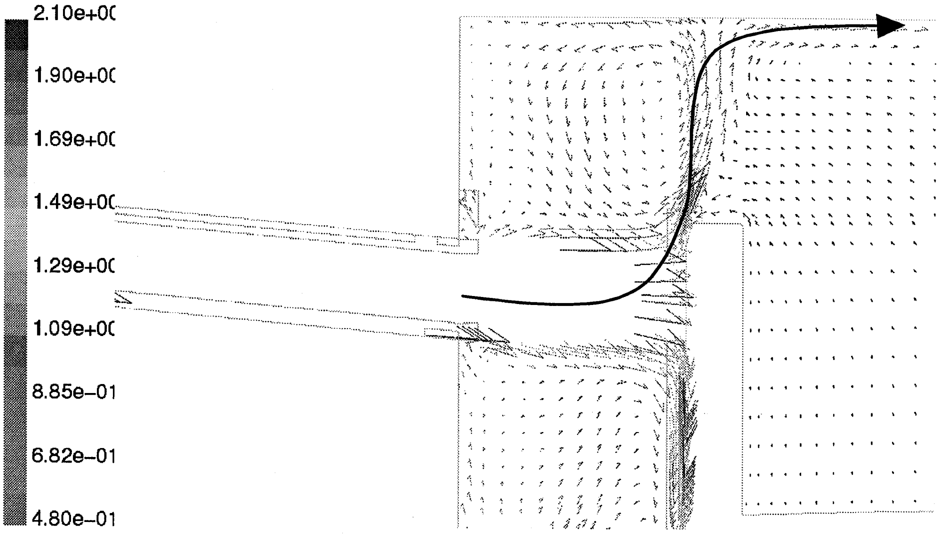


Fig. 9.2 the jet stream hits the wall and some goes right up to the surface and into the tank.

The streams from the different pipes seams to go different ways, why, for example the stream from mix pipe four don't mix with all the others in a appropriate way.

There is a good plug flow in the tanks, just some swirls by the inlets, a few dead zones under the inlet and outlet, but not very big.

- 85 % of tank 1 participates and about 15 % are considered as dead zones.
- 79 % of tank 2 participates and about 21 % are considered as dead zones.
- 79 % of tank 3 participates and about 21 % are considered as dead zones.

To get a view of, how the flow pattern in the facility looks like, we have plotted velocity vectors in the sections that are of interest. In some of the pictures we have chosen not to consider the highest velocities. The higher velocities will dominate the picture so they will take away what we want to show.

9.1 6 m^3/s 2:nd order modeling scheme

This calculation is based on the second order-modelling scheme. The filled arrows represent the main flow pattern in the section.

9.1.1 Tank 1

The jet from the pipe creates a under pressure so the water splits at the tank 1:s inlet. The under pressure sucks the water in tank 1 back to the inlet and goes out at the water surface. In the bottom of the mixing channel, a swirl is generated from the jet in pipe 4.

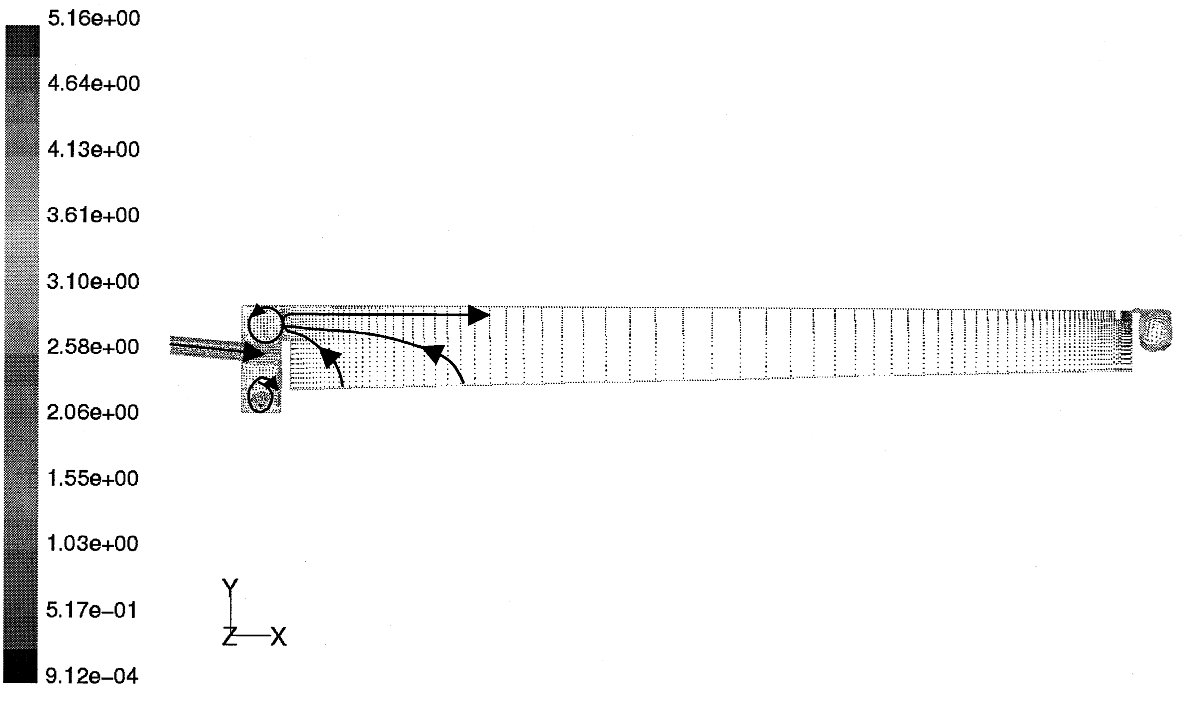


Fig. 9.1.1.1 Velocities and streams in tank one, pipe three

9.1.2 Tank 2

A clockwise eddy is spreading in one third of the tank. The main flow in the tank goes out at the top.

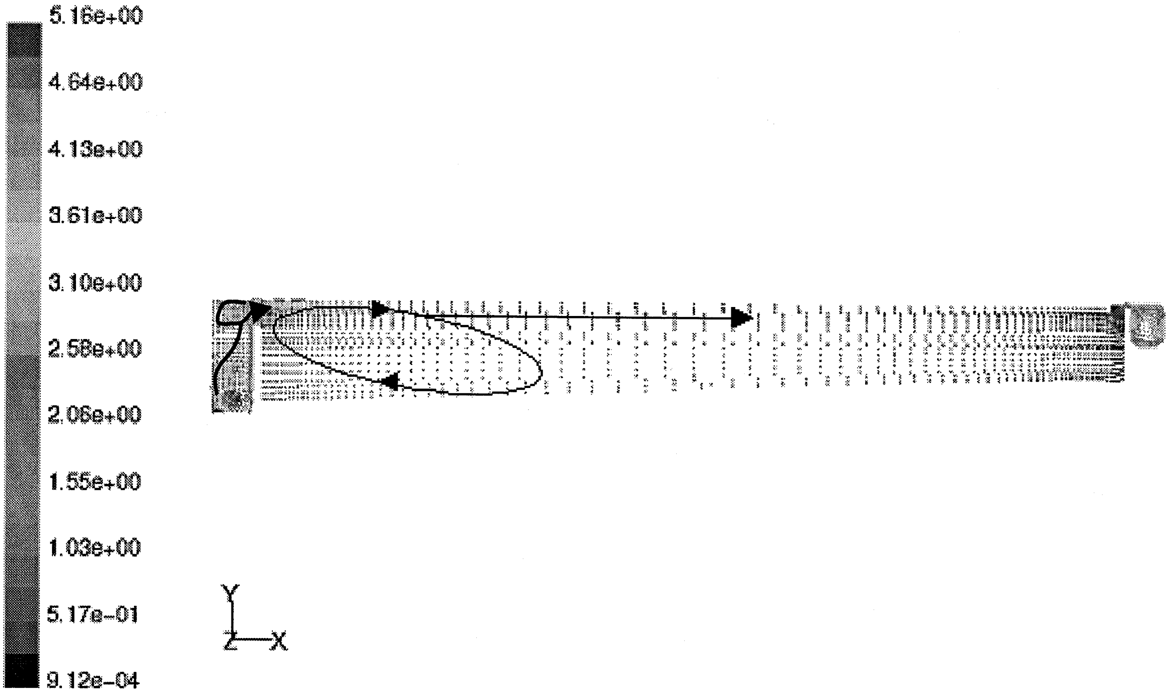


Fig. 9.1.2.1 Velocities and streams in tank two

9.1.3 Tank 3

In tank 3 there are two main eddies with low velocities. In the mixing channel a swirl is spreading almost up to the weir.

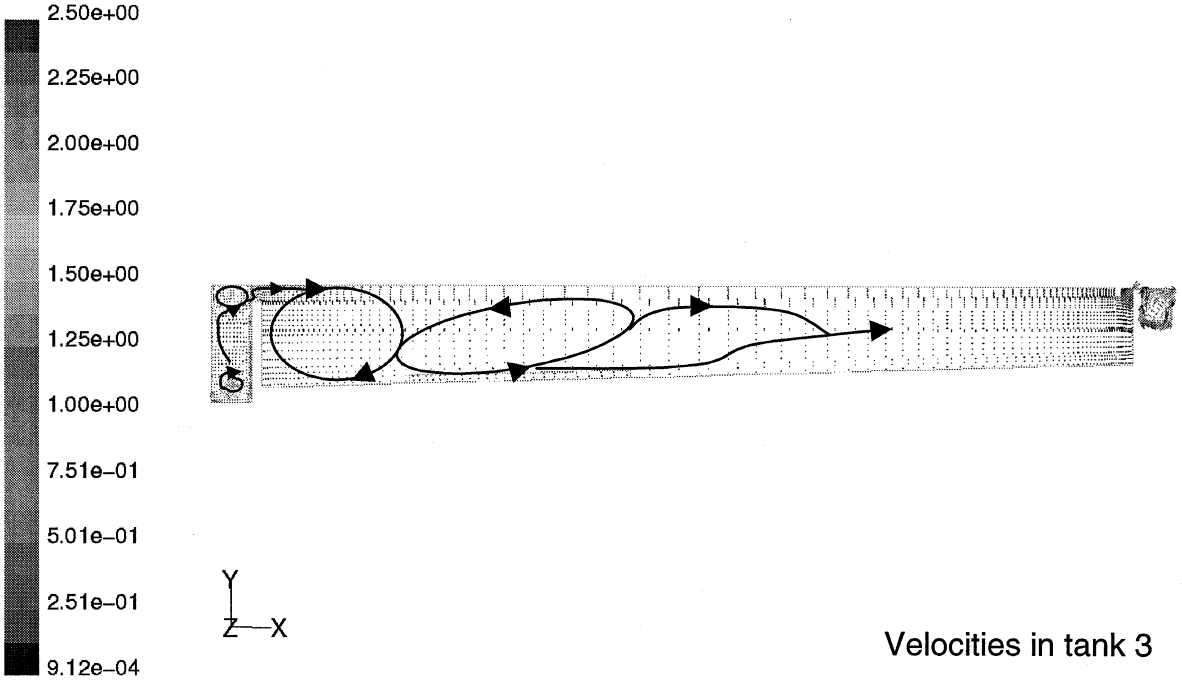


Fig. 9.1.3.1 Velocities and streams in tank three

9.1.4 Mixing channel

In the mixing channel four jets from the pipes are creating big turbulence. A big eddy is generated around pipe3. The impact of pipe 4 is really strong on the flow pattern. The jet is pressing the water up in the channel and

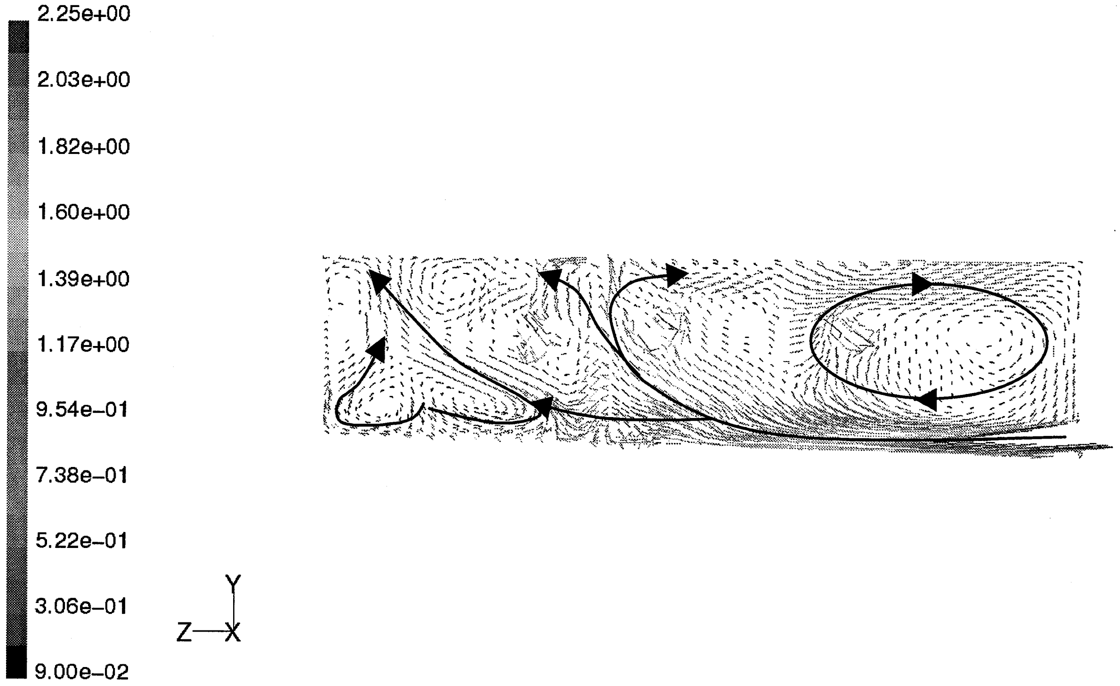


Fig. 9.1.4.1 Velocities and streams in the mix channel. The up going streams will partly go straight into the tanks

The flow from pipe one, two and three hits the walls and then turn up to the surface:

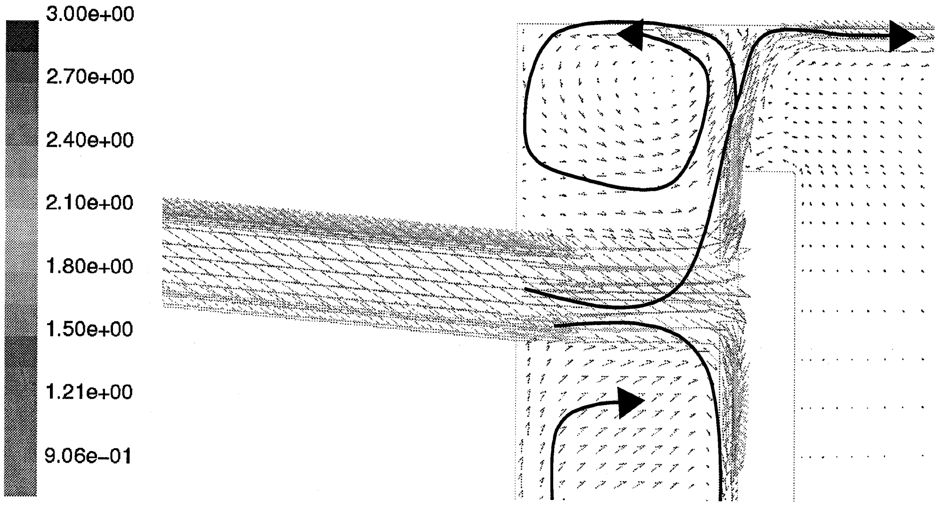


Fig. 9.1.4.2 Velocities and streams in the mix channel at pipe two.

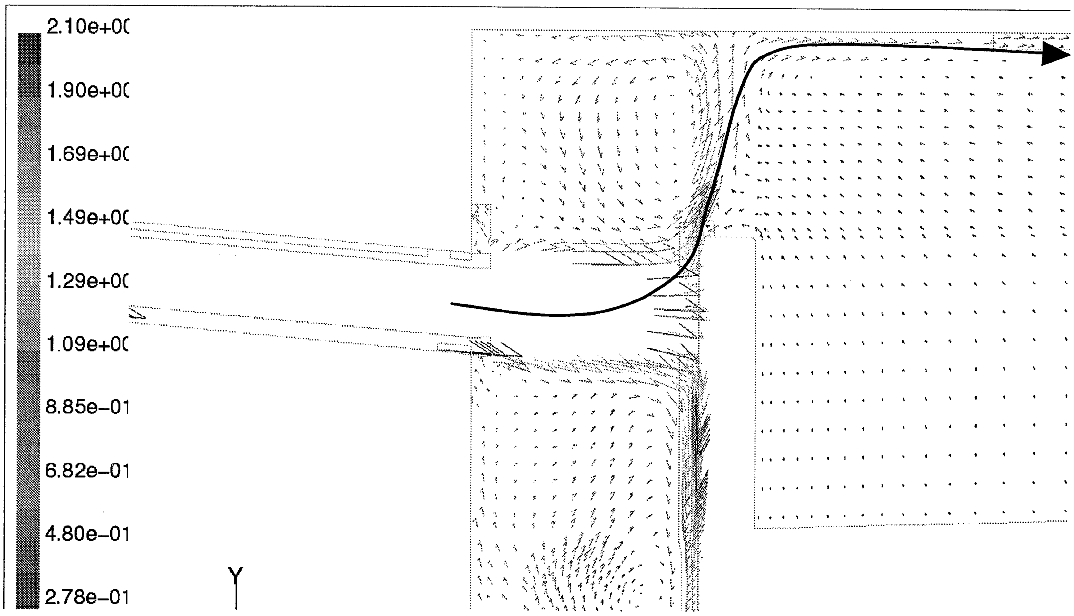


Fig. 9.1.4.2 Velocities and streams in the mix channel at pipe three.

9.1.5 Water surface

In tank 1 the main water goes out along the sides of the tank. In tank 2 there is three main streams where the water goes. The circles with the cross show approximately where the flow splits. One part goes forward and one part goes down and backwards and creates an eddy.

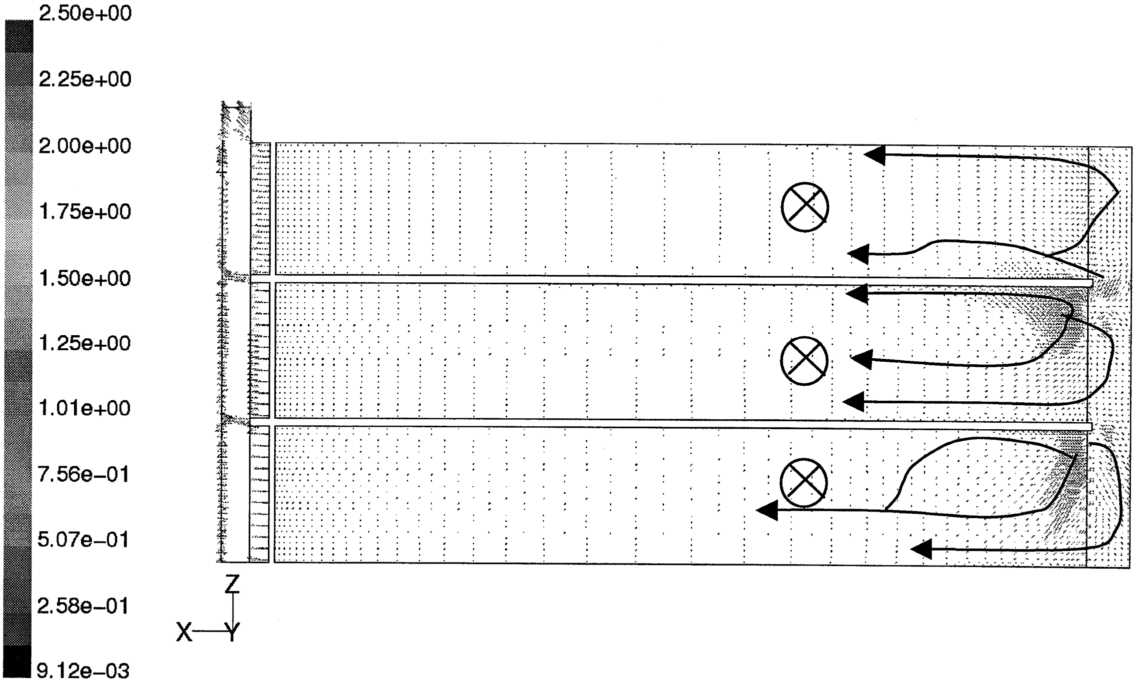


Fig. 9.1.5 Velocities and streams in the mix channel at pipe two.

9.2 6 m3/s 1 order modeling scheme

In this calculation the first order modelling scheme is used. This scheme gets a better convergence but the eddies appear less clear.

9.2.1 Tank 1

An eddy is generated in one third of the tank. In the bottom of the mixing channel a swirl is produced because or the jet from pipe 4. This picture has the same structure as in the 2:nd order-modelling scheme. Quite soon the flow reach a nice plug flow.

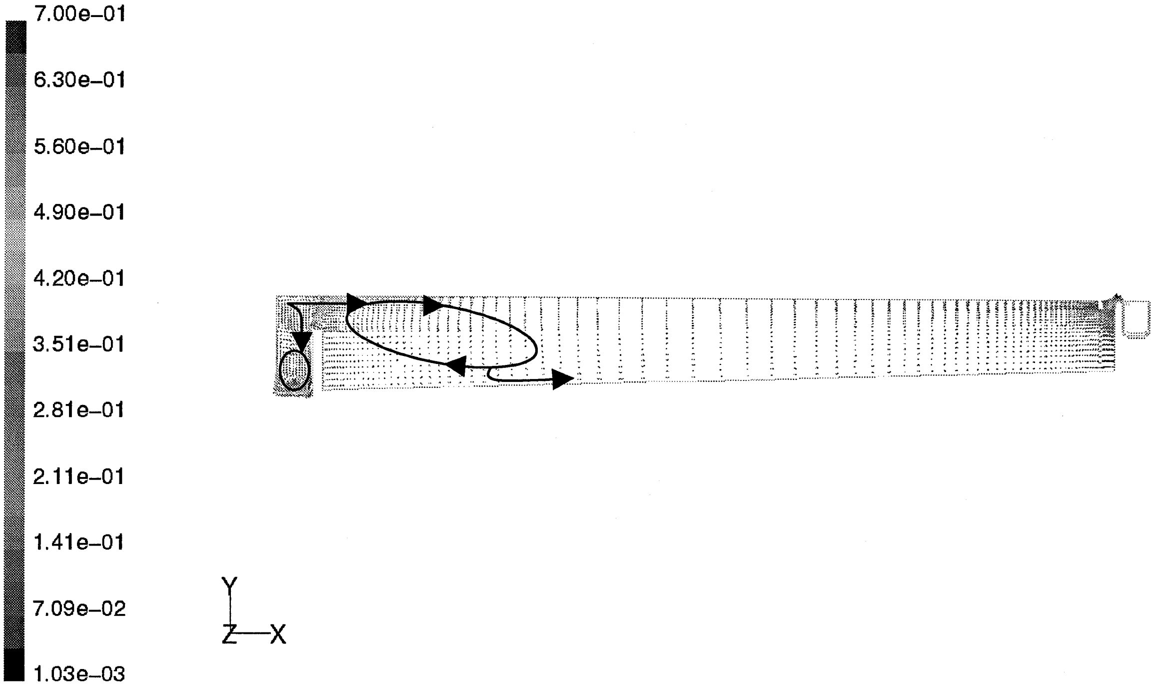


Fig. 9.2.1.1 Velocities and streams in tank 1.

9.2.2 Tank 2

A clockwise eddy is spreading in one third of the tank. It has the same structure as the one in the second order scheme.

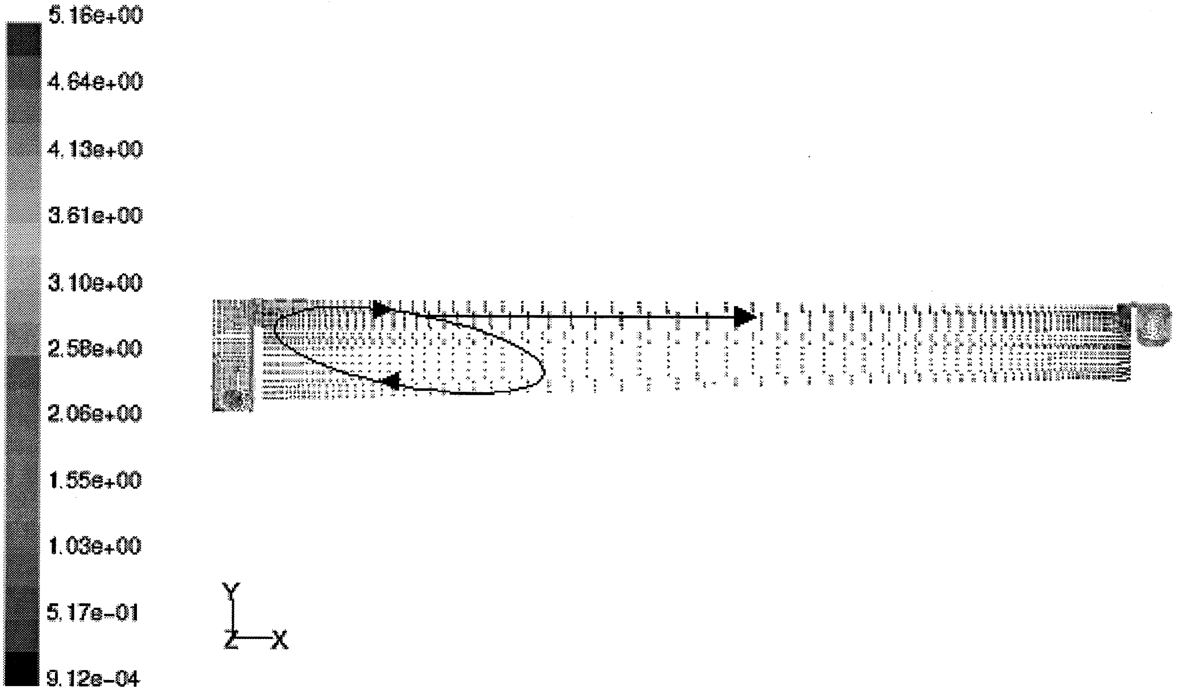


Fig. 9.2.2.1 Velocities and streams in tank 2.

9.2.3 Tank 3

The velocity pattern is the same as in the second order scheme case.

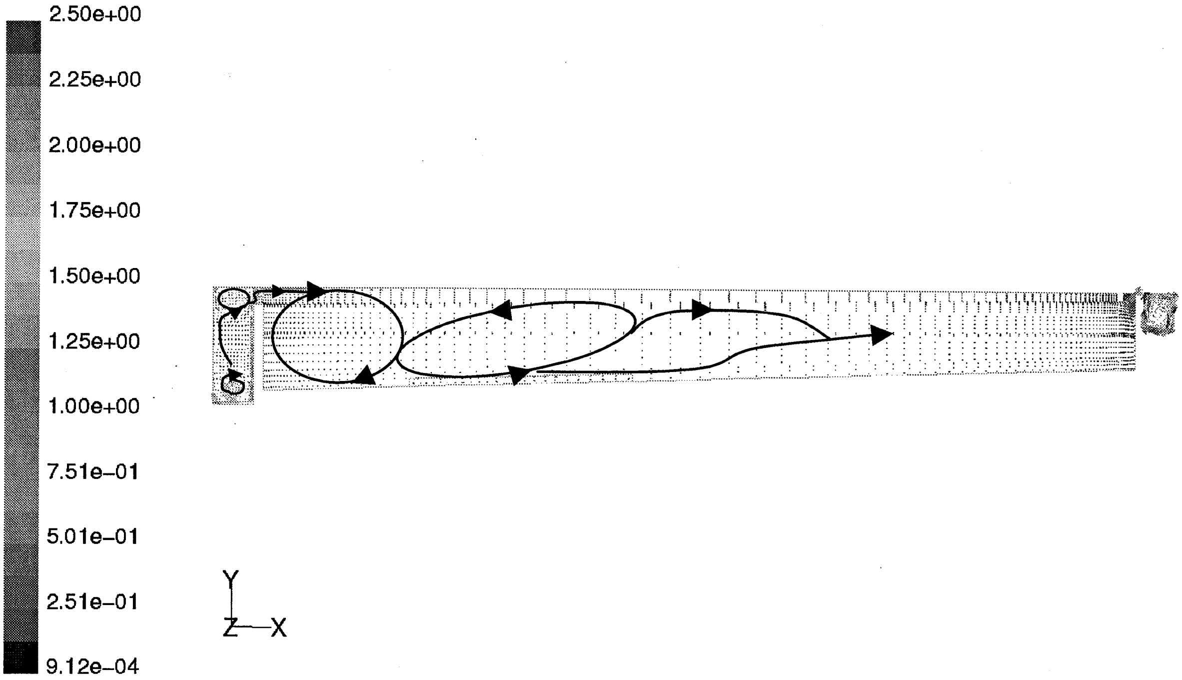


Fig. 9.2.3.1 Velocities and streams in tank 3.

9.2.4 Mixing channel

The velocity pattern has the same structure as in the second order scheme. But the eddies appear less distinctly.

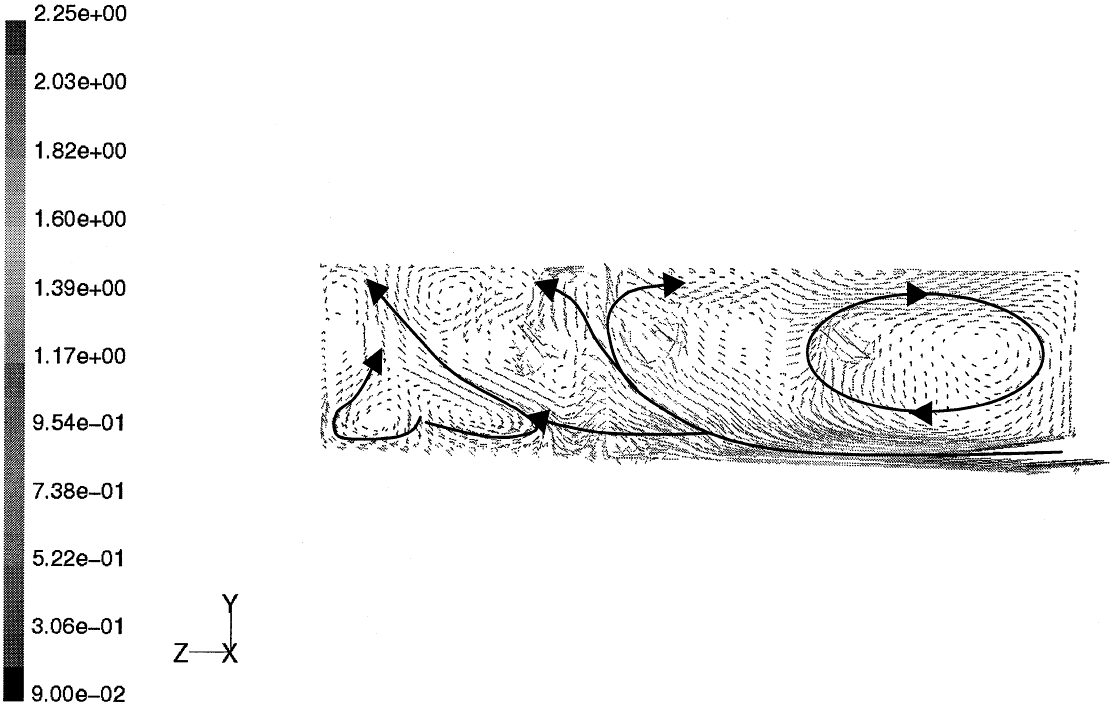


Fig. 9.2.4.1 Velocities and streams in the mixing channel.

9.3 2m3/s and 4m3/s

The flows for these cases have the same structure as in the two other cases. To verify this we have plotted pictures from the same section in tank3. The velocity is of course smaller in the in the two cases with lower flows but the main flow pattern looks the same.

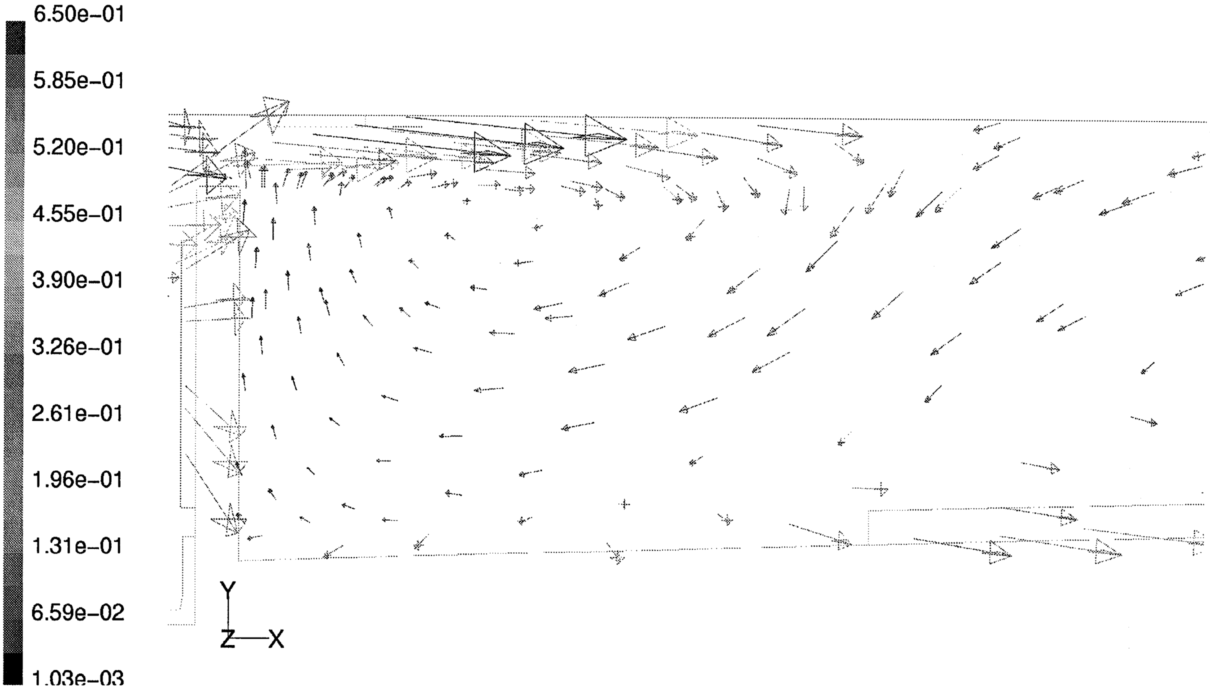


Fig. 9.3.2.1 Velocities and streams in tank 3 with 6 m^3/s at first order scheme

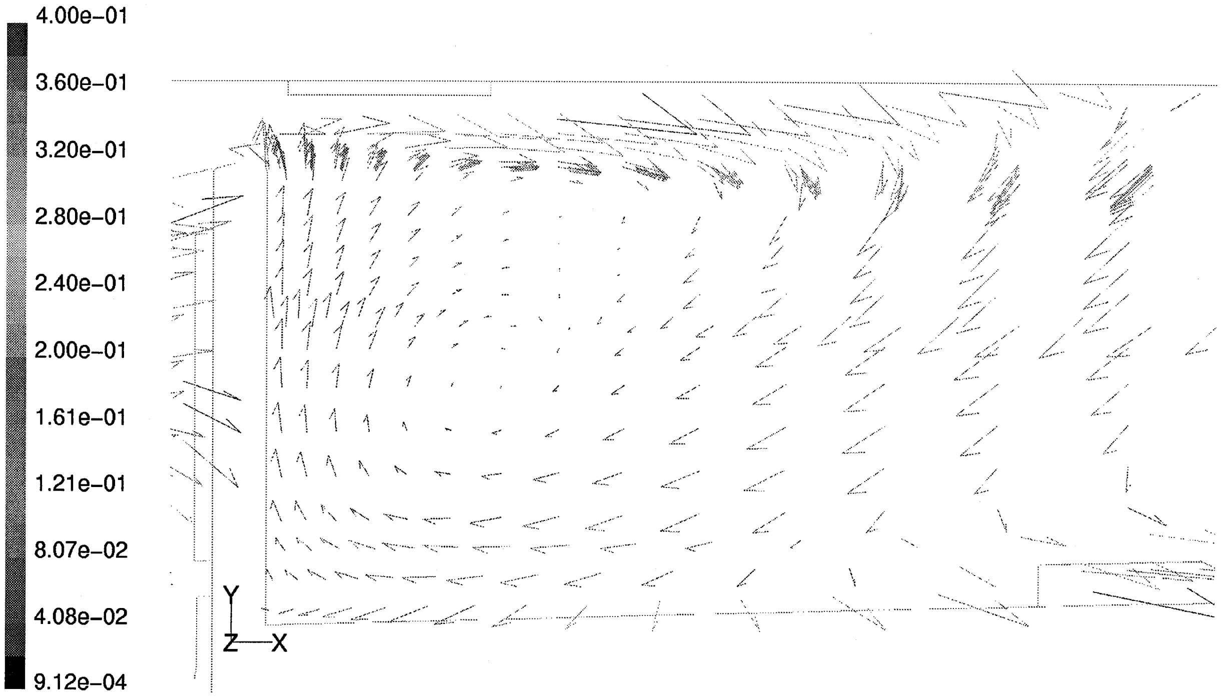


Fig. 9.3.2.2 Velocities and streams in tank 3 with 6 m³/s at a second order scheme

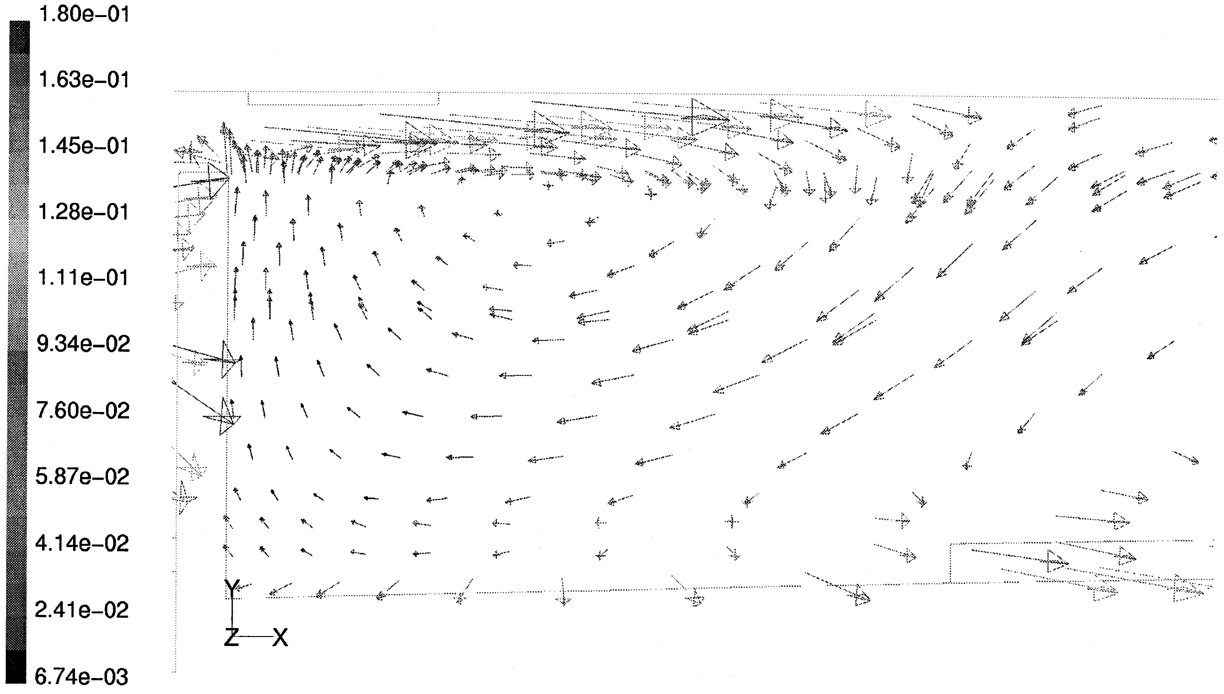


Fig. 9.3.2.3 Velocities and streams in tank 3 with 2 m³/s at first order scheme

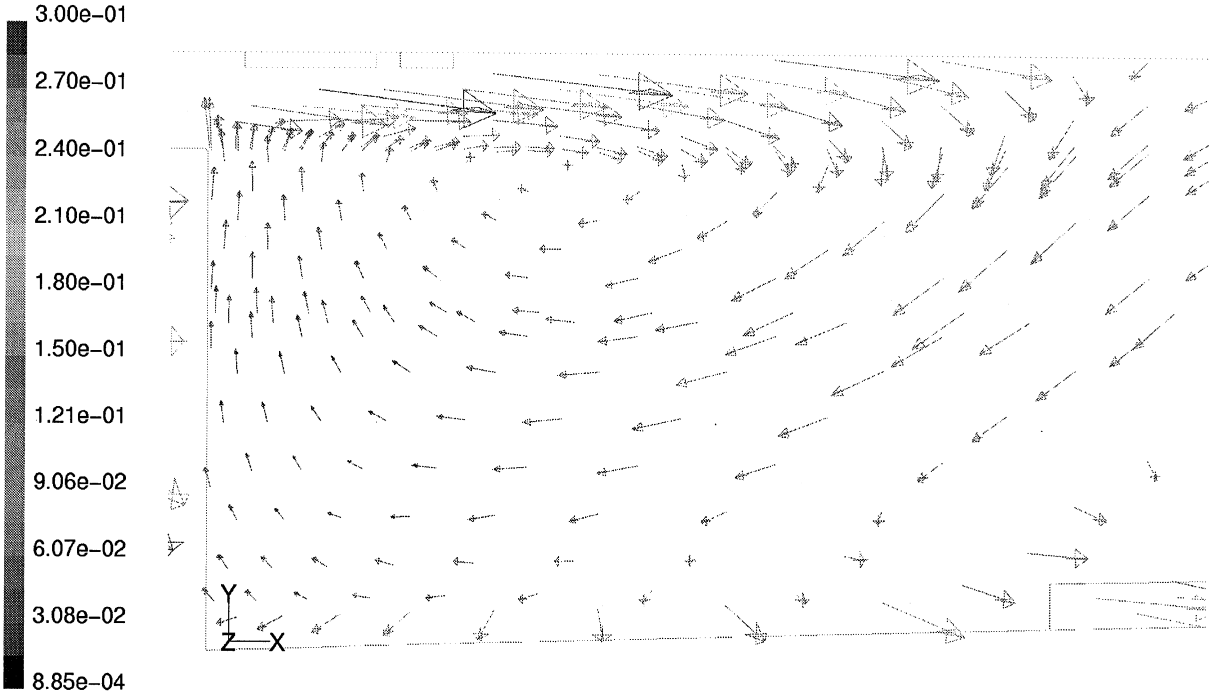


Fig. 9.3.2.4 Velocities and streams in tank 3 with 4 m^3/s at first order scheme

9.4 Summary

9.4.1 The Mixing pipes

The mixing in the pipes has not been studied with sufficient accuracy for high quality estimations. The mixing is probably higher in reality than in this model because of the effect from the polymer pipe that has been simplified in our model. Thou the mixing for high flows are probably relatively small in the mixing pipes as our results claim.

9.4.2 The Mixing channel

In the mixing channel the four pipes create jets that cut through the channel due to its high velocities. The three pipes on the east wall hits the opposite wall and divide the mixing channel in to an upper and a lower whirlpool. The fourth pipe gives the bottom part a nice drive through the channel with a swirl from the other three pipes.

Pipe number three and two hits the wall on the opposite side of the channel and divides in to two beautiful whirlpools. Pipe number one hits the wall and the edge of the inlet to tank one and send its jet into the tank.

9.4.3 The Tanks

In tank one with the lowest weir the effect of the jet has a quite strong impact of the flow pattern. The jet sneaks over the weir and give the tank a nice whirlpool. Most water enters the tank down in the left corner over the weir because of the jet from pipe one. In tank one and two the jets hits the wall, goes up to the surface and enter the tanks.

9.4.4 Outflow channel

The mixing in the outflow channel is very good for high flows; the outlets from the three tanks enter the outflow channel in the surface and create a big and powerful ripple along the first part of the channel.

10 CONCLUSIONS

The conclusions from our calculations are as follows:

- There is a good plug flow in the tanks, accept from the first fourth part, were it's a bit disturbed from the inlets.
- The mixing would be better if the jets didn't stir up to the surface and direct went in to the tanks.
- The flow from the different pipes reach different tanks, and use different parts of the mix channel.
- Only parts of the flow in the mixing channel are getting well mixed.
- The flow is not equally shared between the three tanks

The flow in the system is turbulent, and there are mixing in the system. For smaller flows the mixing and the jet effect, from the mixing pipes and the tank outflows, are reduced. The mixing is strongest in the mixing channel and in the first third in the three tanks and in the outlet channel.

For this system we would like to have a good mix in the mixing channel, and a good plug flow in the tanks. The mixing in the mixing channel is not good enough to make a good mixing for the polymer. To get a better mix it would be vice to kill the jet streams from the pipes, before they reach the tanks. In tank two, too much of the total flow goes along the surface for a good plug flow.

The location of the mixing pipes relatively the inlet weirs determines the pattern of the mixing in the first third part of the tanks and in the mixing channel. To give the system a better function one can:

- Put up a screen that kills the jets before they reach the tanks, to improve the plug flow in the tanks and to create a better mixing in the mix channel.
- Increase the openings in tank two and three to get a better distribution between the three tanks.
- Use a conventional mixing system for the polymer, with a weir by the surface to make sure that we have a good mixing and then focus on creating a good plug flow, instead of deep down pipes.
- Use the favor of the high elevation down to the Don River with over falls between the CSO tank and the mix channel and between the tanks and the storm water tanks to improve the hydraulic function in the system.

There are possibilities that the mixing would be better in our simulations if we simulated the polymer dosing system, but it would anyway be good to kill the jets.

11 SUGGESTIONS OF CONTINOUS WORK

There are things that we did not have time to do and things that we would do different today:

- Take away unnecessary geometric details in the model to simplify the meshing.
- Reduce the number of elements in the mesh before we start the calculations. Now when we now more about the flows pattern we would start calculating with bigger grid size.
- Increase the quality for images from the particle track.

Some easy continuous work on our model would be to:

- Run the particle track from one pipe at a time to see how the flows from each pipe is mixing
- Correct the flows in the model, to the one determined by Dr Jiri Marsalek's scale model.
- Do settling calculations in the tanks

Or a bit more advanced continuous work:

- Add a tank upstream the mix pipes and put a fix water level as the boundary, to see what the flows would be for different levels.
- Use a free water surface in the whole model to observe the surface for different flows.
- Include the polymer dosing system in the model, to get better approximations of mixing and flow.
- Make models of alternative solutions for the system, ex:
  - With a screen to kill the jet effect from the mix pipes
  - With a lower outflow level from the system, with ski boards instead of pipes.

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APPENDIX

Appendix 1

Measurements from the particle tracking

Appendix 2

Validation and calculation of the particle tracking

Appendix 3

Figures and graphs of the flow pattern and residuals

appendix_1

Conc(kg/M^3)	Inl T1	Releace	Releace p4	Timestep	Timestep*Conc	Sum M dw	Sum M up	ABS(dw - up)*M
Realtime(s):	Conc							
0	0,0000	0	0	0	0,000	0,000	201,47	201,47
0,5	0,0000	100	0	0,5	0,000	0,000	201,47	201,47
1	0,0000	100	0	0,5	0,000	0,000	201,47	201,47
1,5	0,0000	100	0	0,5	0,000	0,000	201,47	201,47
2	0,0000	100	0	0,5	0,000	0,000	201,47	201,47
2,5	0,0000	0	0	0,5	0,000	0,000	201,47	201,47
3	0,0001	0	0	0,5	0,000	0,000	201,47	201,47
3,5	0,0008	0	0	0,5	0,000	0,000	201,47	201,47
4	0,0102	0	0	0,5	0,005	0,006	201,47	201,46
4,5	0,0591	0	0	0,5	0,030	0,035	201,46	201,43
5	0,2747	0	0	0,5	0,137	0,172	201,43	201,26
5,5	0,9040	0	0	0,5	0,452	0,624	201,30	200,67
6	2,1057	0	0	0,5	1,053	1,677	200,84	199,17
6,5	4,0028	0	100	0,5	2,001	3,679	199,79	196,11
7	5,8573	0	100	0,5	2,929	6,607	197,79	191,18
7,5	7,1538	0	100	0,5	3,577	10,184	194,86	184,68
8	7,5827	0	100	0,5	3,791	13,976	191,28	177,31
8,5	7,2000	0	0	0,5	3,600	17,576	187,49	169,92
9	6,4402	0	0	0,5	3,220	20,796	183,89	163,10
9,5	5,6500	0	0	0,5	2,825	23,621	180,67	157,05
10	5,0214	0	0	0,5	2,511	26,131	177,85	151,72
11	3,7324	0	0	1	3,732	29,864	175,34	145,47
12	2,7818	0	0	1	2,782	32,645	171,60	138,96
14	1,6555	0	0	2	3,311	35,956	168,82	132,87
16	1,0500	0	0	2	2,100	38,056	165,51	127,46
18	0,8300	0	0	2	1,660	39,716	163,41	123,70
20	0,7349	0	0	2	1,470	41,186	161,75	120,57
22	0,8449	0	0	2	1,690	42,876	160,28	117,41
24	1,0637	0	0	2	2,127	45,003	158,59	113,59
26	1,2825	0	0	2	2,565	47,568	156,46	108,90
28	1,4913	0	0	2	2,983	50,551	153,90	103,35
30	1,6500	0	0	2	3,300	53,851	150,92	97,07
32	1,8300	0	0	2	3,660	57,511	147,62	90,11
34	1,9876	0	0	2	3,975	61,486	143,96	82,47
36	2,1579	0	0	2	4,316	65,802	139,98	74,18
38	2,2700	0	0	2	4,540	70,342	135,67	65,32
41	2,4228	0	0	3	7,268	77,610	131,13	53,52
46	2,3530	0	0	5	11,765	89,375	123,86	34,48
51	2,1044	0	0	5	10,522	99,897	112,09	12,20
56	1,5100	0	0	5	7,550	107,447	101,57	5,88
61	1,2000	0	0	5	6,000	113,447	94,02	19,43
66	1,0555	0	0	5	5,278	118,725	88,02	30,70
71	0,9777	0	0	5	4,889	123,613	82,74	40,87
80	0,8000	0	0	9	7,200	130,813	77,85	52,96
95	0,7000	0	0	15	10,500	141,313	70,65	70,66
105	0,6000	0	0	10	6,000	147,313	60,15	87,16
115	0,5000	0	0	10	5,000	152,313	54,15	98,16
125	0,4000	0	0	10	4,000	156,313	49,15	107,16
135	0,4000	0	0	10	4,000	160,313	45,15	115,16
145	0,4000	0	0	10	4,000	164,313	41,15	123,16
155	0,3000	0	0	10	3,000	167,313	37,15	130,16
170	0,3000	0	0	15	4,500	171,813	34,15	137,66
185	0,2000	0	0	15	3,000	174,813	29,65	145,16
200	0,1638	0	0	15	2,457	177,270	26,65	150,62
215	0,1298	0	0	15	1,947	179,217	24,20	155,02
230	0,1046	0	0	15	1,569	180,786	22,25	158,54
245	0,0869	0	0	15	1,304	182,090	20,68	161,41
260	0,0749	0	0	15	1,124	183,213	19,38	163,83
280	0,0647	0	0	20	1,294	184,507	18,25	166,25
300	0,0570	0	0	20	1,140	185,647	16,96	168,69
320	0,0500	0	0	20	1,000	186,647	15,82	170,83
340	0,0439	0	0	20	0,878	187,525	14,82	172,70
360	0,0395	0	0	20	0,790	188,315	13,94	174,37
390	0,0367	0	0	30	1,101	189,416	13,15	176,26
420	0,0356	0	0	30	1,068	190,484	12,05	178,43
450	0,0336	0	0	30	1,008	191,492	10,98	180,51
480	0,0307	0	0	30	0,921	192,413	9,98	182,44
510	0,0283	0	0	30	0,849	193,262	9,05	184,21
540	0,0264	0	0	30	0,792	194,054	8,21	185,85
570	0,0246	0	0	30	0,738	194,792	7,41	187,38
630	0,0206	0	0	60	1,236	196,028	6,68	189,35
690	0,0173	0	0	60	1,038	197,066	5,44	191,63
750	0,0144	0	0	60	0,864	197,930	4,40	193,53
870	0,0102	0	0	120	1,224	199,154	3,54	195,62
990	0,0070	0	0	120	0,840	199,994	2,31	197,68
1170	0,0042	0	0	180	0,756	200,750	1,47	199,28
1470	0,0017	0	0	300	0,510	201,260	0,72	200,54
2070	0,0003	0	0	600	0,180	201,440	0,21	201,23
2670	0,0000	0	0	600	0,026	201,466	0,03	201,44
3570	0,0000	0	0	900	0,002	201,468	0,00	201,47
4770	0,0000	0	0	1200	0,000	201,468	0,00	201,47
6570	0,0000	0	0	1800	0,000	201,468	0	201,4683407
					201,4683407	201,4683455		

Mass (kg)	Sum T1 inl	Sum T2 inl	Sum T3 inl	Sum T1 out	Sum T2 out	Sum T3 out
Real time (s):	kg	kg	kg	kg	kg	kg
0	0	0	0	0	0	0
2	7,8E-09	1,52E-10	1,3E-11	0	0	0
4	0,0232	0,003	0,001	0	0	0
6	4,0634	1,7678	0,9394	0	0	0
8	15,1866	22,0794	16,8096	0	0	0
10	10,2242	22,769	20,2344	0	0	0
12	8,2437	12,4155	12,1887	0	0	0
16	3,8224	5,6676	4,7956	0	0	0
20	2,9396	6,1656	5,8696	0	1,3684E-35	0
24	4,8832	9,828	7,6924	1,85E-34	1,3684E-35	0
28	6,8188	11,7468	7,4824	1,85E-34	1,3684E-35	0
32	7,1024	10,1816	7,2752	4E-26	4E-22	0
36	15,1053	15,4854	12,7939	7E-23	7E-19	0
46	23,53	12,726	15,505	1E-16	1E-13	1E-36
56	14,276	7,227	12,397	1E-12	0,000000001	1E-28
66	12,666	6,312	10,6956	1,2E-09	0,0000012	1,2E-23
80	11,6	5,8	8,7	0,000000145	0,00145	1,45E-17
95	8,75	3,75	6,25	0,0000125	0,0125	1,25E-13
105	6	2	4	0,0001	0,3	1E-10
115	5	2	3	0,001	0,8	0,000000001
125	4	1	3	0,004	1,4	0,0000004
135	4	1	3	0,007	2	0,000001
145	4	1	3	0,009	2,5	0,0001
155	3,75	1,25	2,5	0,0125	3,625	0,000875
170	4,5	3	3	0,015	4,725	0,0105
185	3	3	3	0,015	4,65	0,072
200	2,457	2,175	2,1525	0,039	4,3545	0,294
215	1,947	1,9425	1,7055	0,129	3,9345	0,8805
230	1,569	1,692	1,3875	0,3795	3,567	1,761
245	1,3035	1,473	1,203	0,9045	3,2415	2,835
260	1,31075	1,51725	1,30025	2,058	3,47725	4,5185
280	1,294	1,528	1,42	4,33	3,694	6,424
300	1,14	1,392	1,354	6,344	3,626	6,856
320	1	1,314	1,256	7,74	3,768	6,56
340	0,878	1,272	1,152	8,284	4,062	5,914
360	0,9875	1,57	1,3475	10,175	5,5375	6,6175
390	1,101	1,878	1,56	11,088	7,392	7,287
420	1,068	1,863	1,53	10,086	7,851	7,479
450	1,008	1,806	1,452	9,774	7,884	8,1
480	0,921	1,71	1,35	10,02	7,575	8,634
510	0,849	1,587	1,275	10,38	7,113	8,754
540	0,792	1,464	1,218	10,431	6,66	8,451
570	1,107	2,025	1,7325	15,003	9,441	11,862
630	1,236	2,358	2,04	16,902	11,646	13,914
690	1,038	2,082	1,806	13,86	10,884	12,444
750	1,296	2,754	2,376	16,992	15,003	16,326
870	1,224	2,844	2,46	15,24	15,672	16,524
990	1,05	2,715	2,34	12,81	14,205	15,54
1170	1,008	2,928	2,52	11,904	14,664	16,608
1470	0,765	2,835	2,475	9,27	13,77	16,2
2070	0,18	1,02	0,9	2,16	4,86	6
2670	0,03225	3	3	3,75	1,425	1,875
3570	0,00252	0,0546	0,05145	0,0315	0,21	0,315
4770	0,000006	0,0045	0,0045	0,00015	0,015	0,03
6570	0	0	0	0	0	0
Total mass	212,049326	218,97855	218,4985	220,1482626	215,5462012	219,0869764

Control of mass fraction

T1(inl-out)	T2(inl-out)	T3(inl-out)
-8,098936638	3,432348799	-0,5884764

T1(inl-out)/T1inl	Γ2(inl-out)/T2in	Γ3(inl-out)/T3inl
0,961806355	0,984325639	0,997306726
OK >95%	OK >95%	OK >95%
Safe side!	Safe side!	Safe side!

Flow calculations :

Mixpipes :

$Q_{mixp1} := 1.4482$ $Q_{mixp2} := 1.4482$ $Q_{mixp3} := 1.4482$ $Q_{mixp4} := 1.594465$

$Q_{mixp\_tot} := Q_{mixp1} + Q_{mixp2} + Q_{mixp3} + Q_{mixp4}$

$Q_{mixp\_tot} = 5.939$

$n_1 := \frac{Q_{mixp1}}{Q_{mixp\_tot}}$ $n_2 := \frac{Q_{mixp2}}{Q_{mixp\_tot}}$ $n_3 := \frac{Q_{mixp3}}{Q_{mixp\_tot}}$ $n_4 := \frac{Q_{mixp4}}{Q_{mixp\_tot}}$

$n_1 = 0.244$ $n_2 = 0.244$ $n_3 = 0.244$ $n_4 = 0.268$

Inlets :

$Q_{in1} := 2.07921$ $Q_{in2} := 1.903617$ $Q_{in3} := 1.811515$

$Q_{tot\_in} := Q_{in1} + Q_{in2} + Q_{in3}$

$Q_{tot\_in} = 5.794$

$n_{in1} := \frac{Q_{in1}}{Q_{tot\_in}}$ $n_{in2} := \frac{Q_{in2}}{Q_{tot\_in}}$ $n_{in3} := \frac{Q_{in3}}{Q_{tot\_in}}$

$n_{in1} = 0.359$ $n_{in2} = 0.329$ $n_{in3} = 0.313$

Tank outlets:

$Q_{out1} := 2.120805$ $Q_{out2} := 1.985746$ $Q_{out3} := 1.846631$

$Q_{out1} = 2.121$ $Q_{out2} = 1.986$ $Q_{out3} = 1.847$

$Q_{tot\_out} := Q_{out1} + Q_{out2} + Q_{out3}$

$Q_{tot\_out} = 5.953$

$n_{out1} := \frac{Q_{out1}}{Q_{tot\_out}}$ $n_{out2} := \frac{Q_{out2}}{Q_{tot\_out}}$ $n_{out3} := \frac{Q_{out3}}{Q_{tot\_out}}$

$n_{out1} = 0.356$ $n_{out2} = 0.334$ $n_{out3} = 0.31$

Outlet:

$Q_{outlet} := 5.891249$

$n_{m1} := \frac{n_{in1} + n_{out1}}{2}$ $n_{m2} := \frac{n_{in2} + n_{out2}}{2}$ $n_{m3} := \frac{n_{in3} + n_{out3}}{2}$

$n_{m1} = 0.358$ $n_{m2} = 0.331$ $n_{m3} = 0.311$

Validation of particle tracking

Tank 1

$Q_{tank1} := 0.358 \cdot 6 \frac{m^3}{s}$ Flow in tank 1, 35.8 % of total flow, see appendix 3

$W_{tank1} := 7m$ Average with in tank 1

$L_{tank1} := 43m$ Average with in tank 1

$H_{tank1} := 4.1m$ Average with in tank 1

$V_{tank1} := W_{tank1} \cdot L_{tank1} \cdot H_{tank1}$ $V_{tank1} = 1.234 \times 10^3 m^3$

$T_{in1} := 54s$

$T_{out1} := 550s$

$T_{cent1} := T_{out1} - T_{in1}$ T_{cent1} = Real delay time

$T_{cent1} = 496 s$

$T_{nom1} := \frac{V_{tank1}}{Q_{tank1}}$ T_{nom1} = Nominal, theoretical delay time

$T_{nom1} = 574.534 s$

$T_1 := \frac{T_{cent1}}{T_{nom1}}$

$T_1 = 0.863$

Tank 2

$Q_{tank2} := 0.331 \cdot 6 \frac{m^3}{s}$ Flow in tank 2, 33.1 % of total flow

$W_{tank2} := 7.15m$ Average with in tank 2

$L_{tank2} := 43m$ Average with in tank 2

$H_{tank2} := 4.1m$ Average with in tank 2

$V_{tank2} := W_{tank2} \cdot L_{tank2} \cdot H_{tank2}$ $V_{tank2} = 1.261 \times 10^3 \, m^3$

$T_{in2} := 36s$

$T_{out2} := 535s$

$T_{cent2} := T_{out2} - T_{in2}$

$T_{cent2} = 499\,s$ T_{cent2} = Real delay time

$T_{nom2} := \frac{V_{tank2}}{Q_{tank2}}$ T_{nom2} = nominal delay time

$T_{nom2} = 634.716\,s$

$T_2 := \frac{T_{cent2}}{T_{nom2}}$

$T_2 = 0.786$

Tank 3

$Q_{tank3} := 0.311 \cdot 6 \frac{m^3}{s}$ Flow in tank 3, 31.1 % of total flow

$W_{tank3} := 7.15m$ Average with in tank 3

$L_{tank3} := 43m$ Average with in tank 3

$H_{tank3} := 4.1m$ Average with in tank 3

$V_{tank3} := W_{tank3} \cdot L_{tank3} \cdot H_{tank3}$ $V_{tank3} = 1.261 \times 10^3 m^3$

$T_{in3} := 50s$

$T_{out3} := 590s$

$T_{cent3} := T_{out3} - T_{in3}$

$T_{cent3} = 540 s$ T_{cent3} = Real delay time

$T_{nom3} := \frac{V_{tank3}}{Q_{tank3}}$ T_{nom3} = nominal delay time

$T_{nom3} = 675.533 s$

$T_3 := \frac{T_{cent3}}{T_{nom3}}$

$T_3 = 0.799$

Mix channel

$Q_{tot\_in} := Q_{tank1} + Q_{tank2} + Q_{tank3}$

$T_{in\_mixch\_veighted} := 2.5s$

$$T_{out\_mixch\_veighted} := \frac{\left(Q_{tank1} \cdot T_{in1}\right)}{Q_{tot\_in}} + \frac{\left(Q_{tank2} \cdot T_{in2}\right)}{Q_{tot\_in}} + \frac{\left(Q_{tank3} \cdot T_{in3}\right)}{Q_{tot\_in}}$$

$T_{cent\_mixch\_veighted} := T_{out\_mixch\_veighted} - T_{in\_mixch\_veighted}$

$T_{cent\_mixch\_veighted} = 44.298\ s$

$V_{mixch} := 275.1m^3$

$$Q_{mixch} := 5.94 \frac{m^3}{s}$$

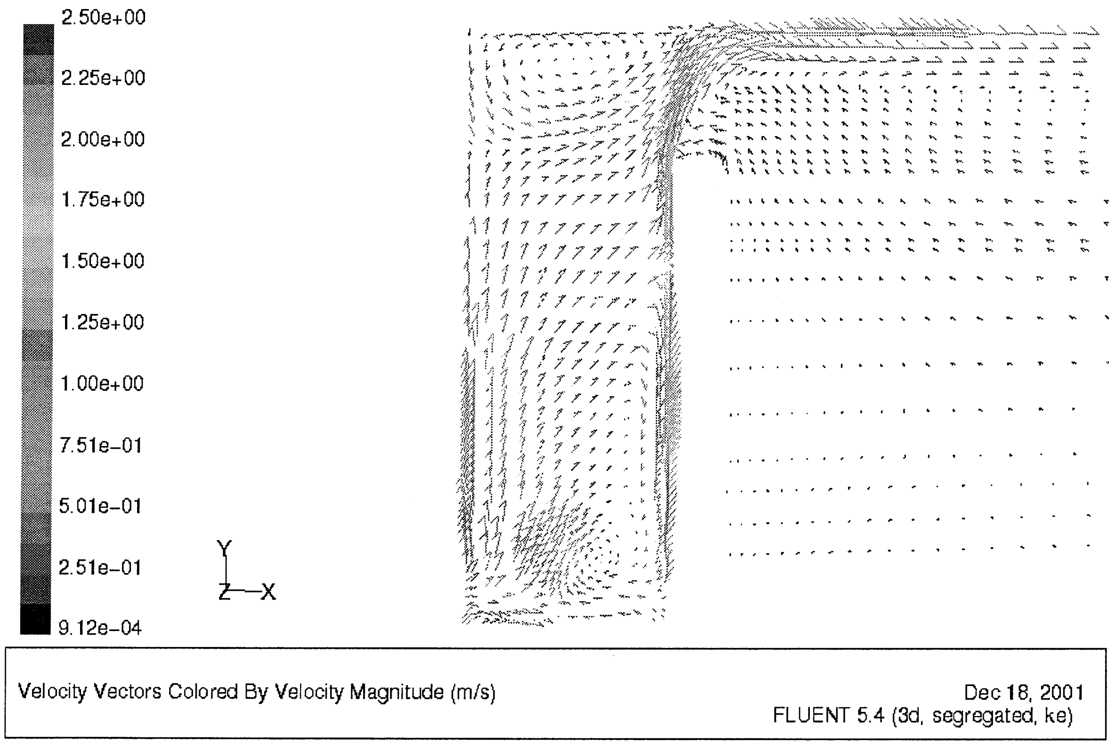
$$T_{mixch\_nom} := \frac{V_{mixch}}{Q_{mixch}}$$

$T_{mixch\_nom} = 46.313\ s$

$$T_{mixch} := \frac{T_{cent\_mixch\_veighted}}{T_{mixch\_nom}}$$

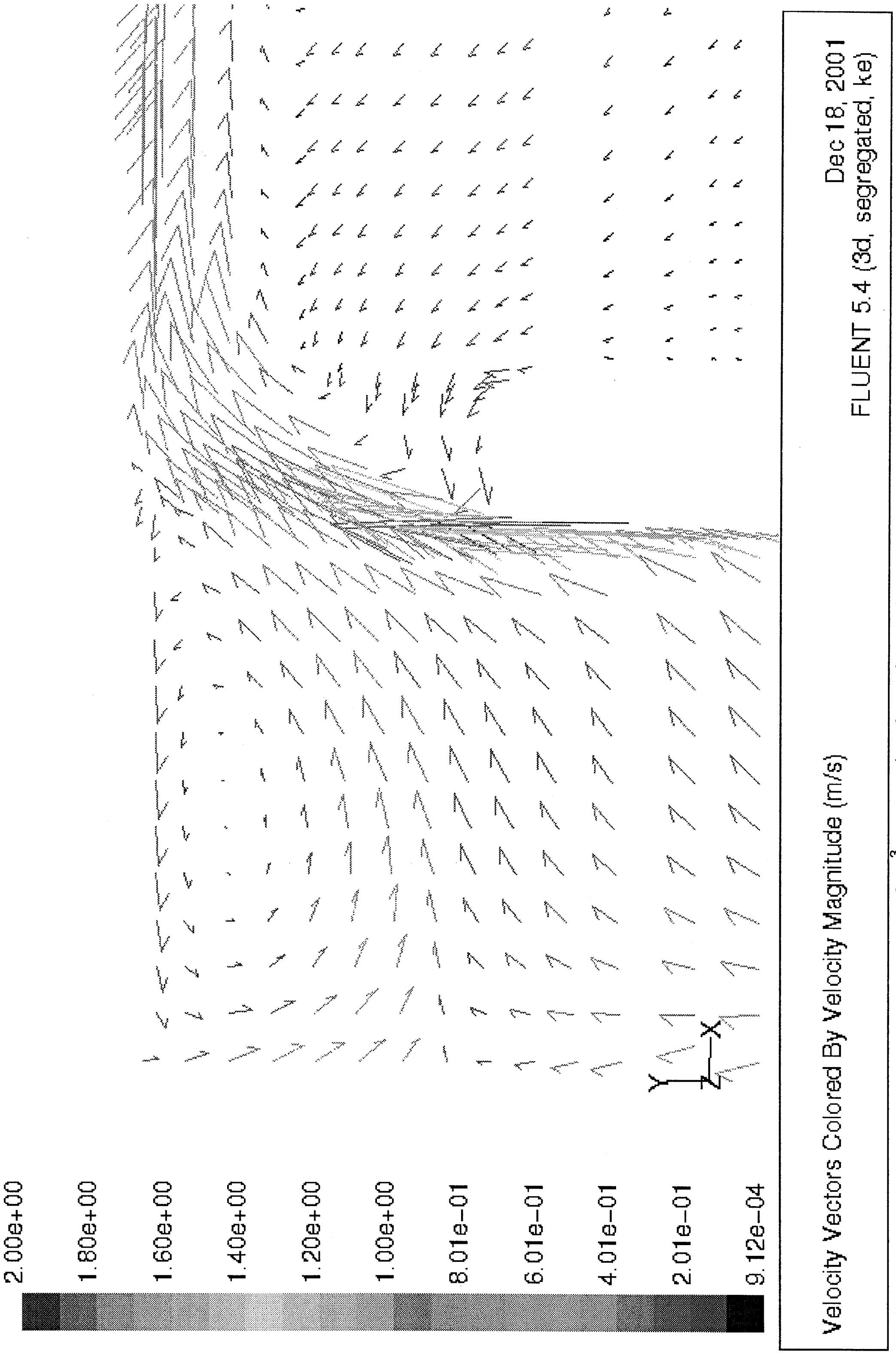
$T_{mixch} = 0.956$

Appendix_3



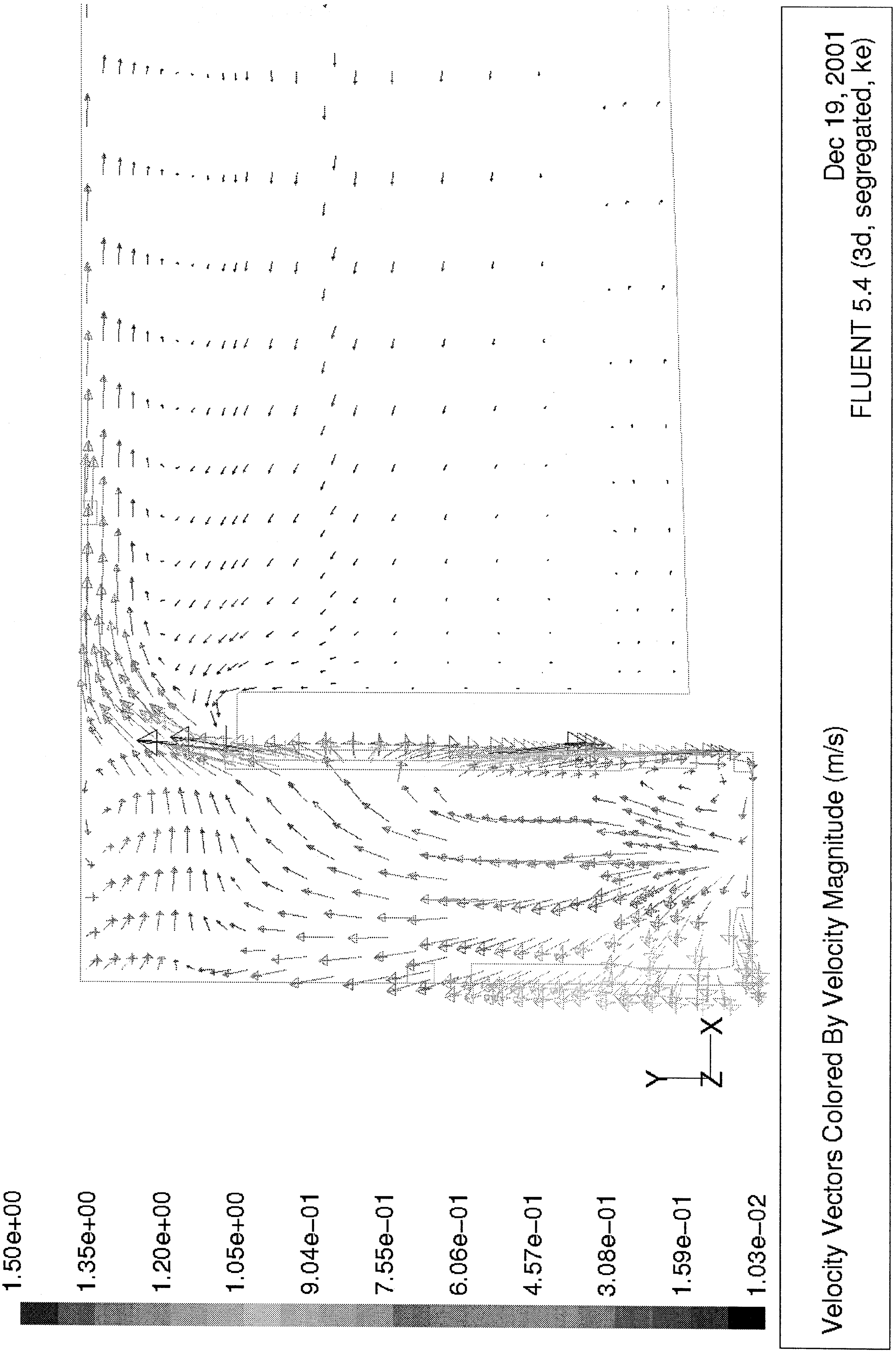
6 m^3 , second order scheme by mix pipe 2.

Appendix_3



6 m^3 , second order scheme by mix pipe 2.

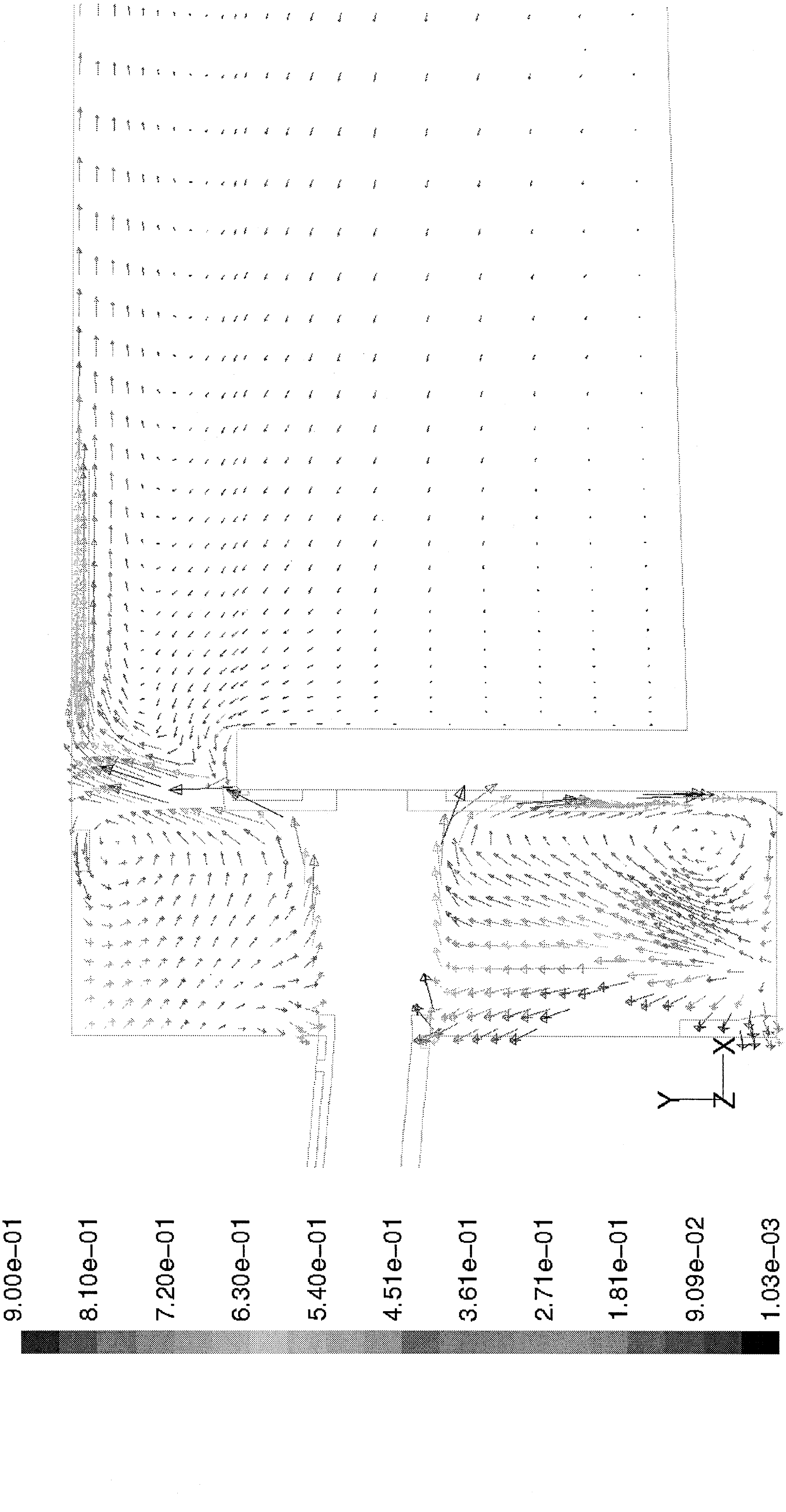
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

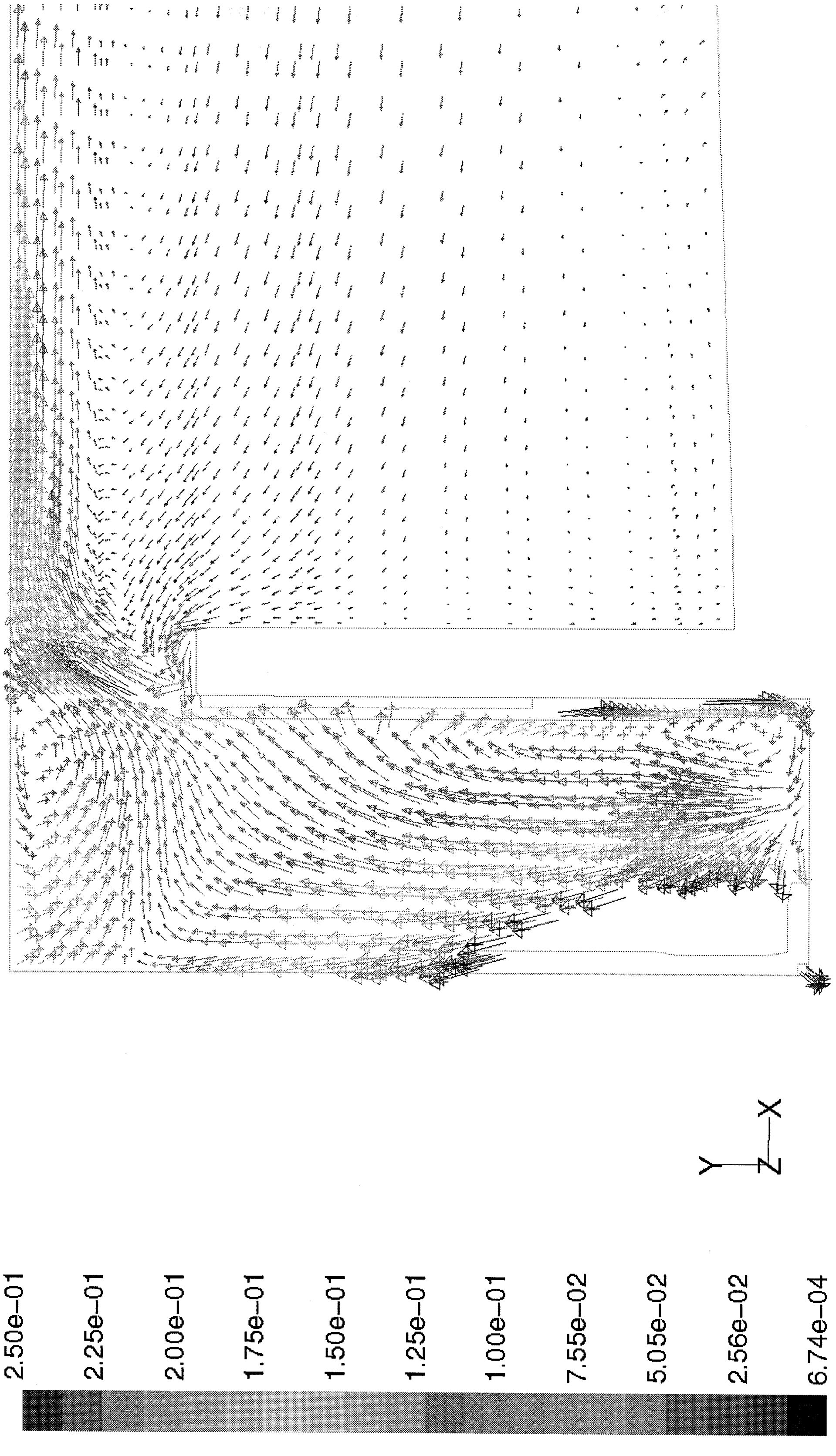
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

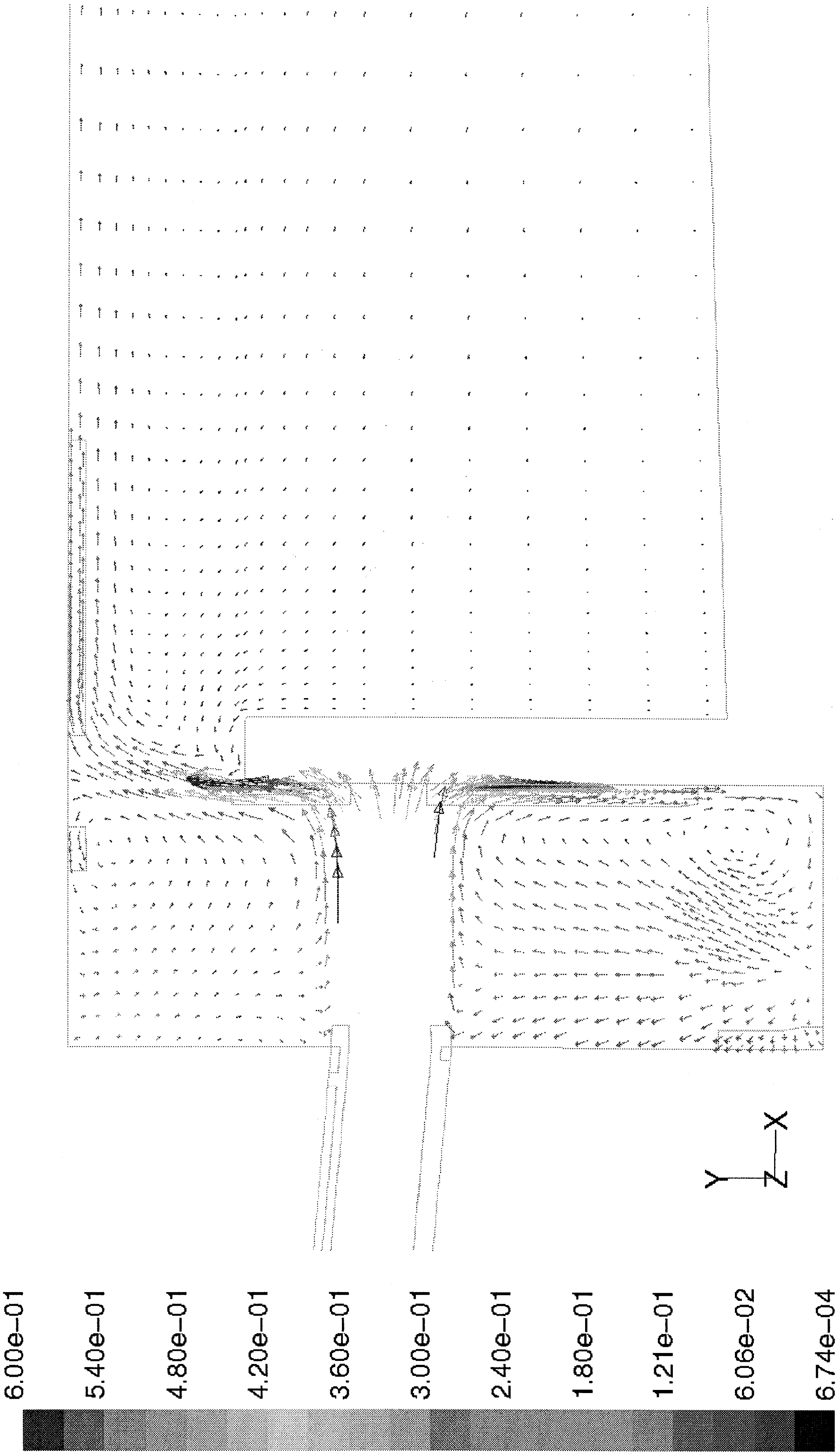
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

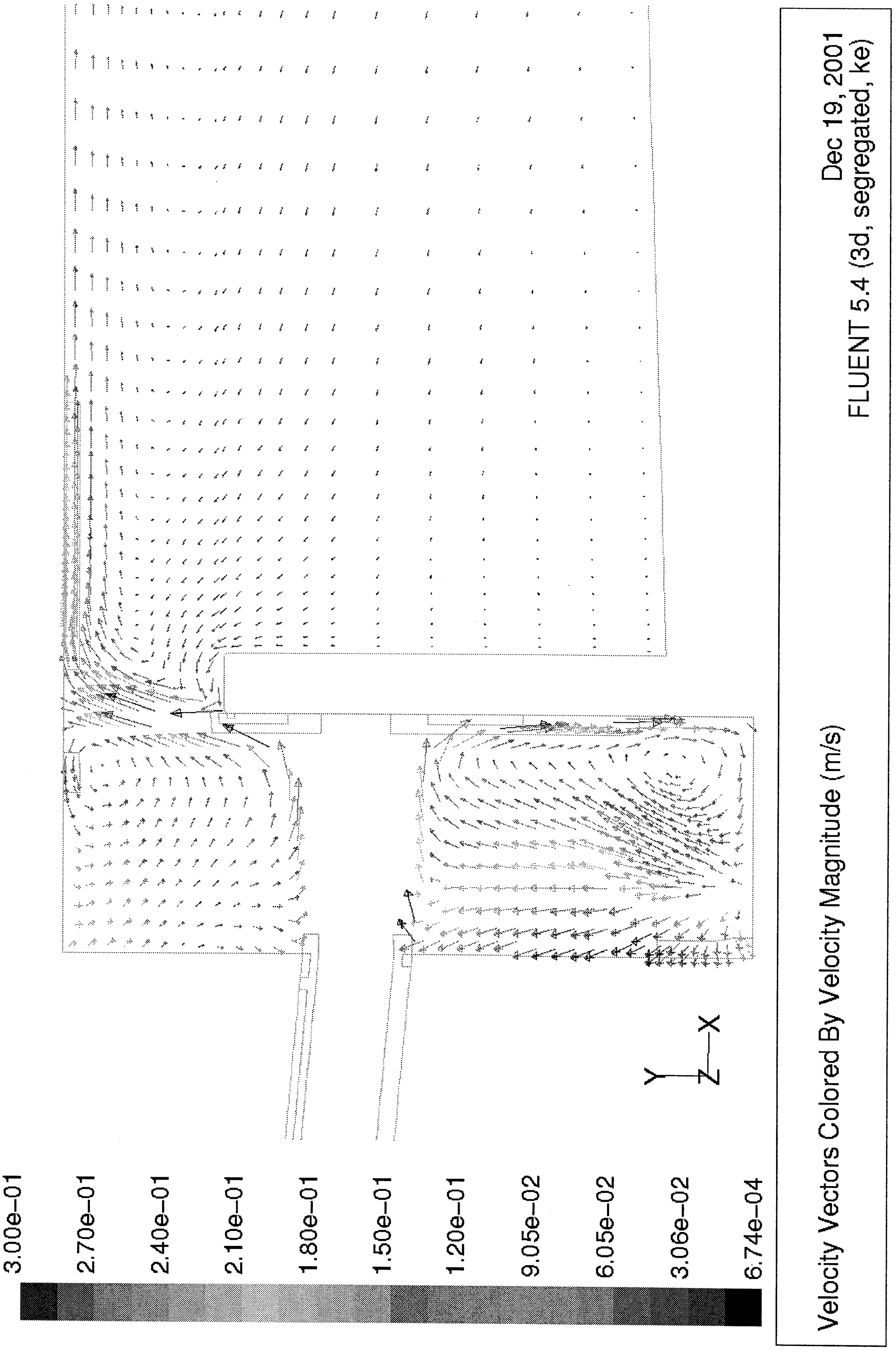
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

Appendix_3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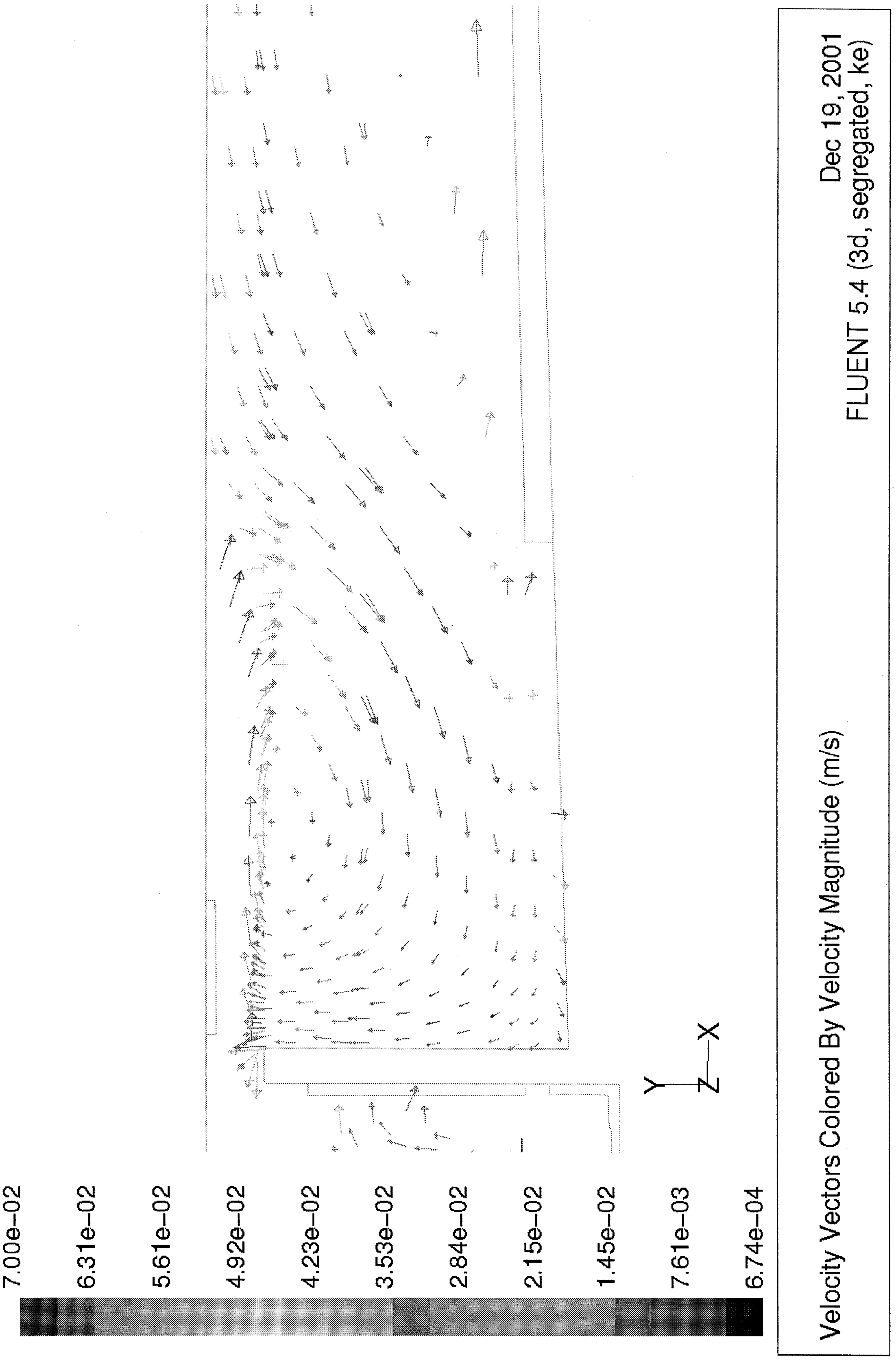
2.40e-01
2.10e-01
1.80e-01
1.50e-01
1.20e-01
9.05e-02
6.05e-02
3.06e-02
6.74e-04
Y
Z
X
Velocity Vectors Colored By Velocity Magnitude (m/s)
Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

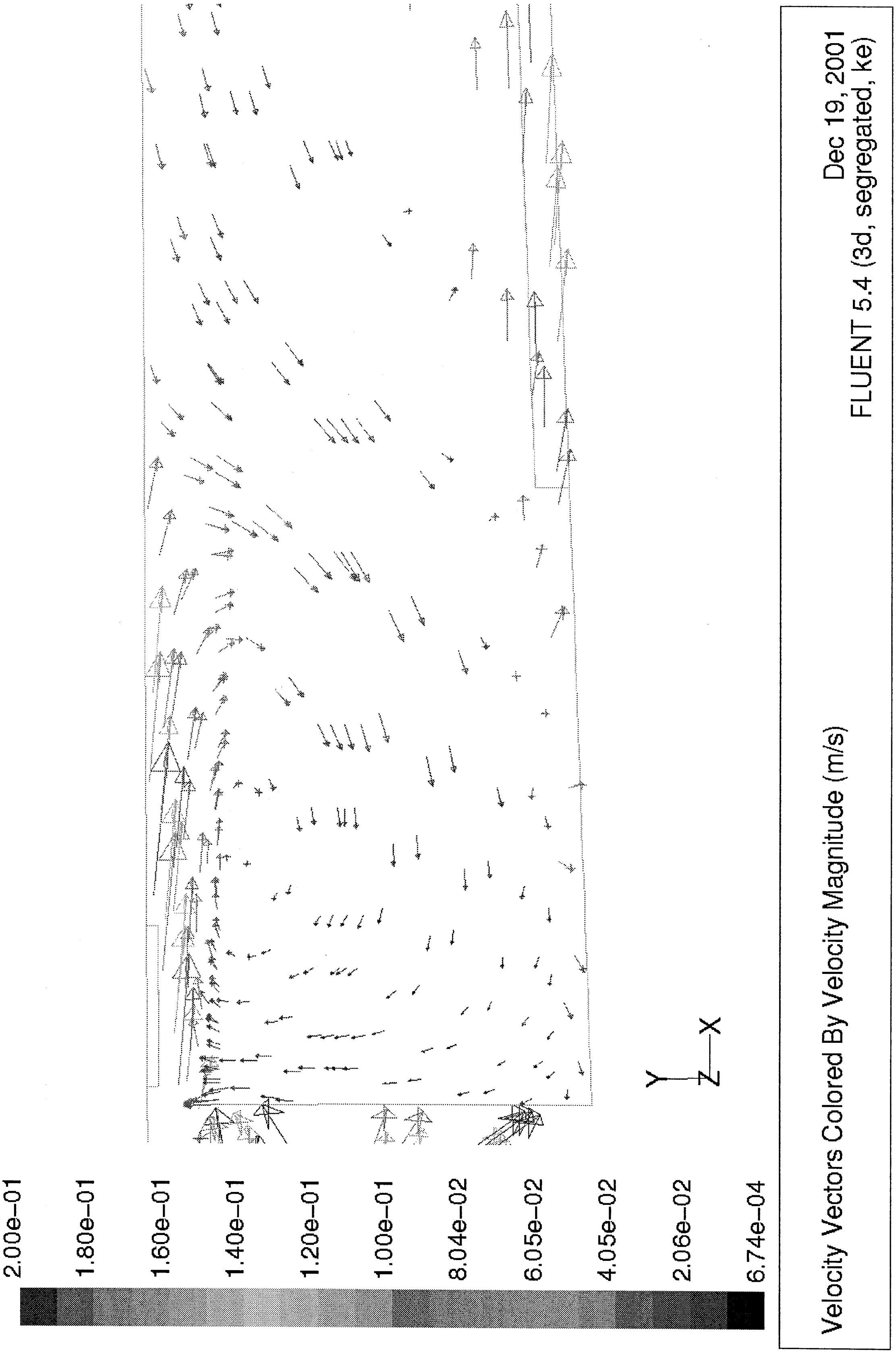
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

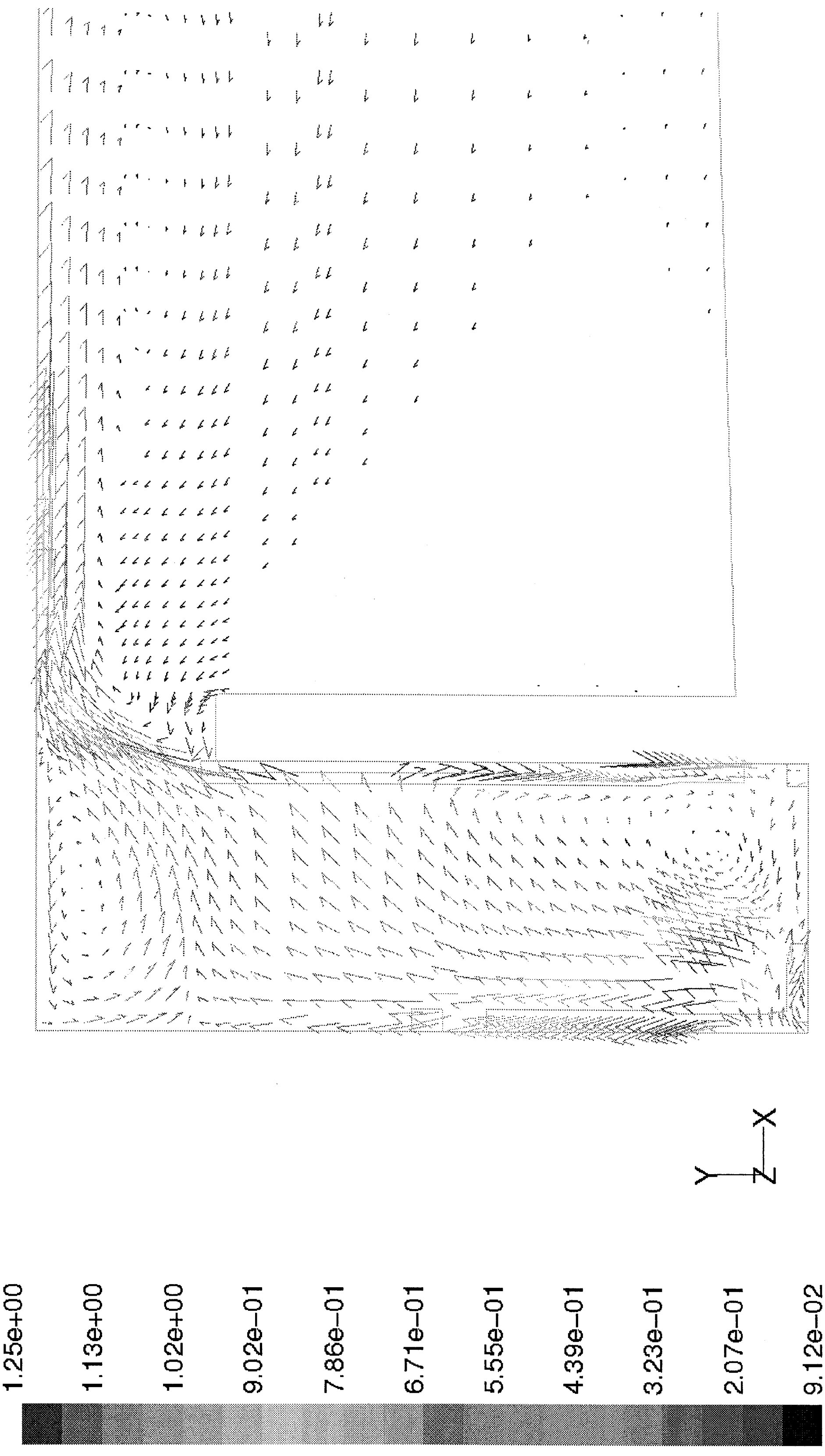
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

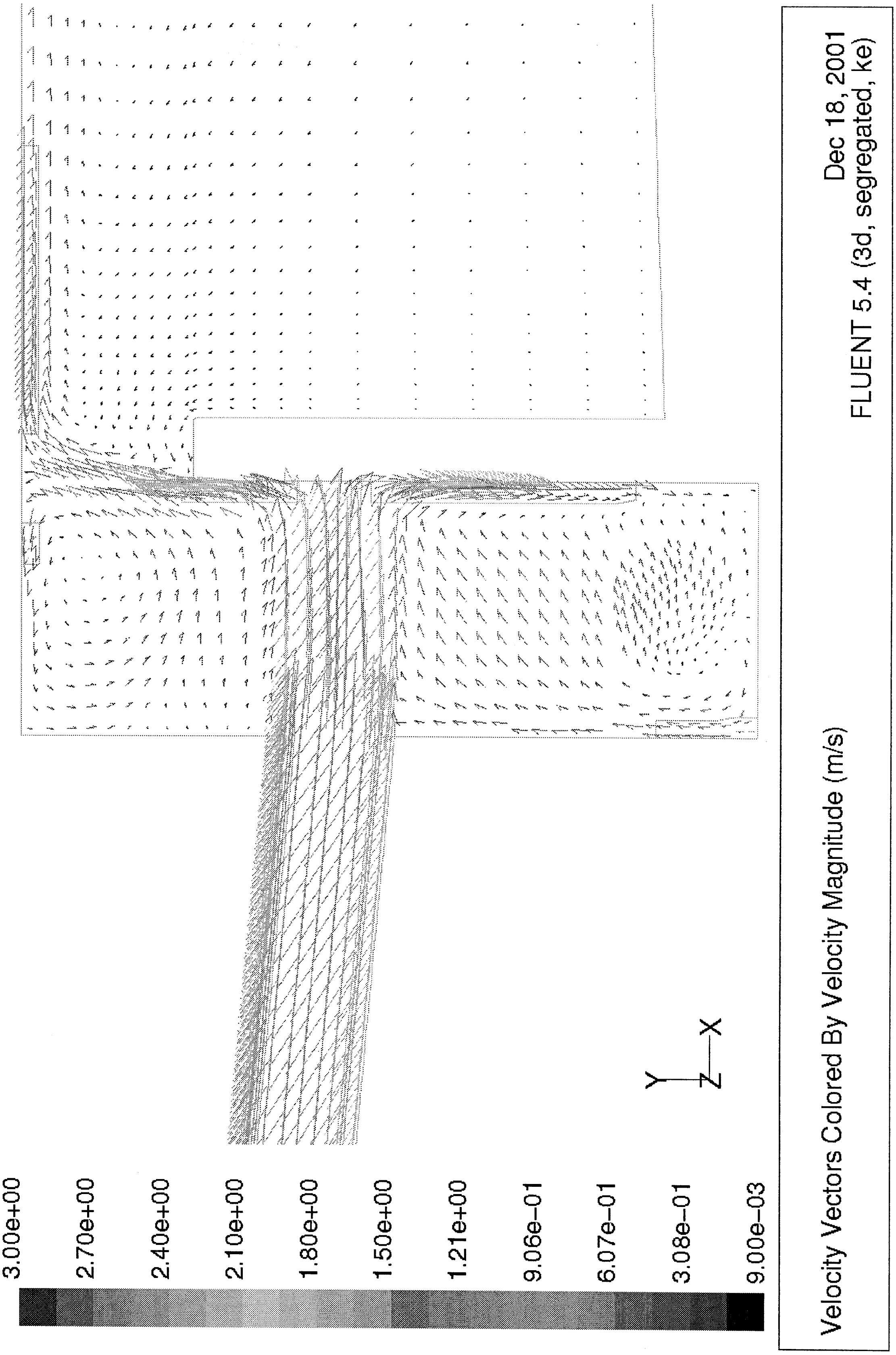
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 18, 2001
FLUENT 5.4 (3d, segregated, ke)

Appendix_3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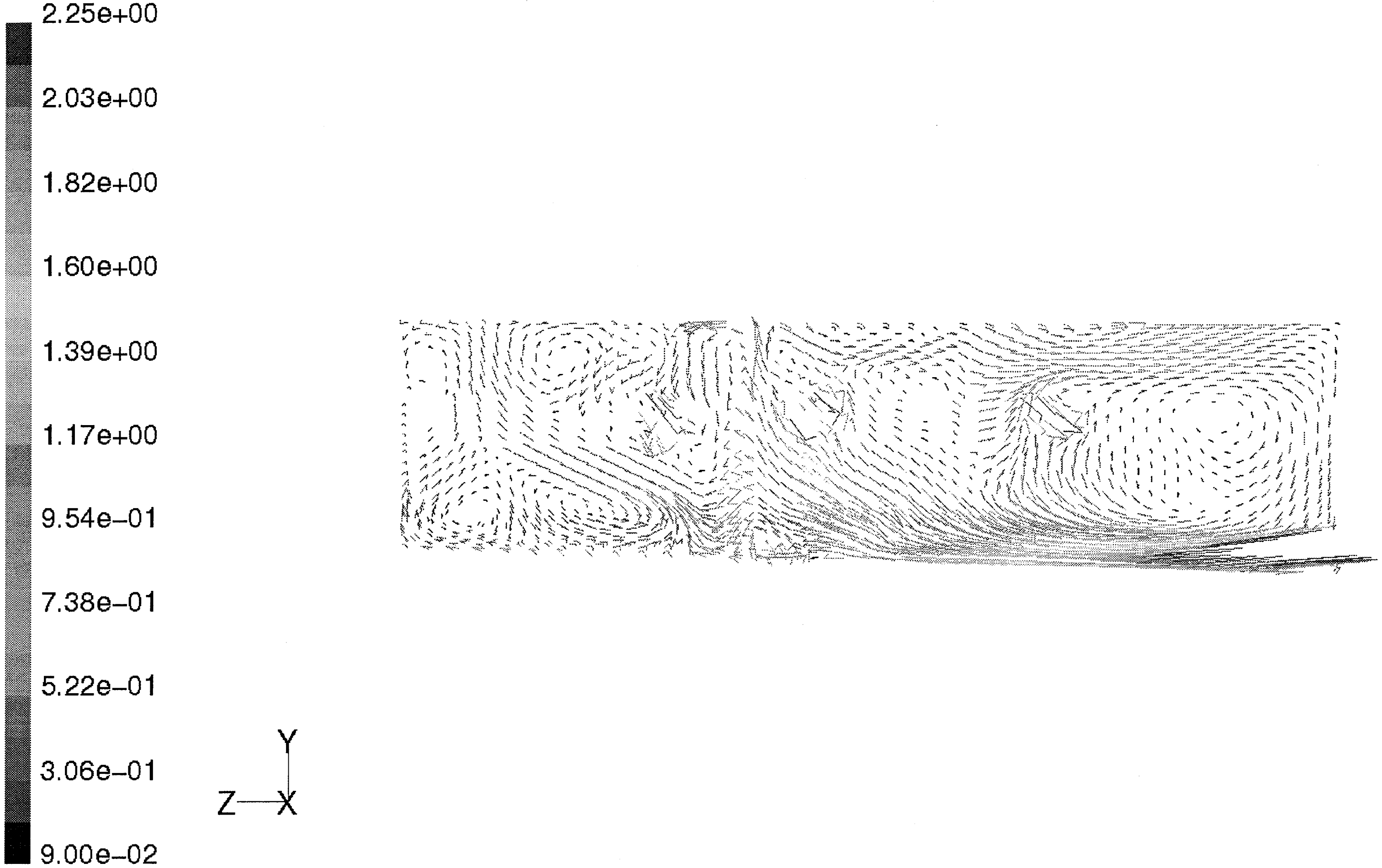
2.40e+00
2.10e+00
1.80e+00
1.50e+00
1.21e+00
9.06e-01
6.07e-01
3.08e-01
9.00e-03
Y
Z
X
Velocity Vectors Colored By Velocity Magnitude (m/s)
Dec 18, 2001
FLUENT 5.4 (3d, segregated, ke)

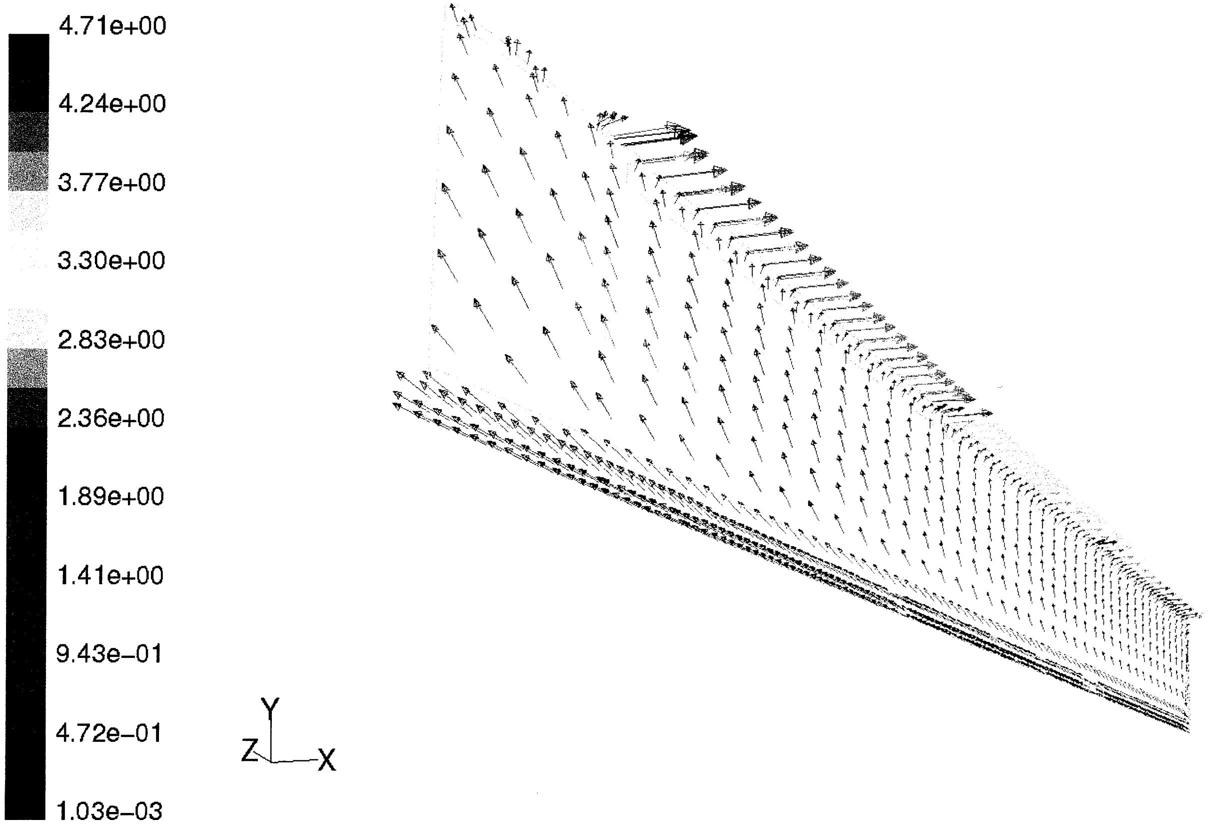
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

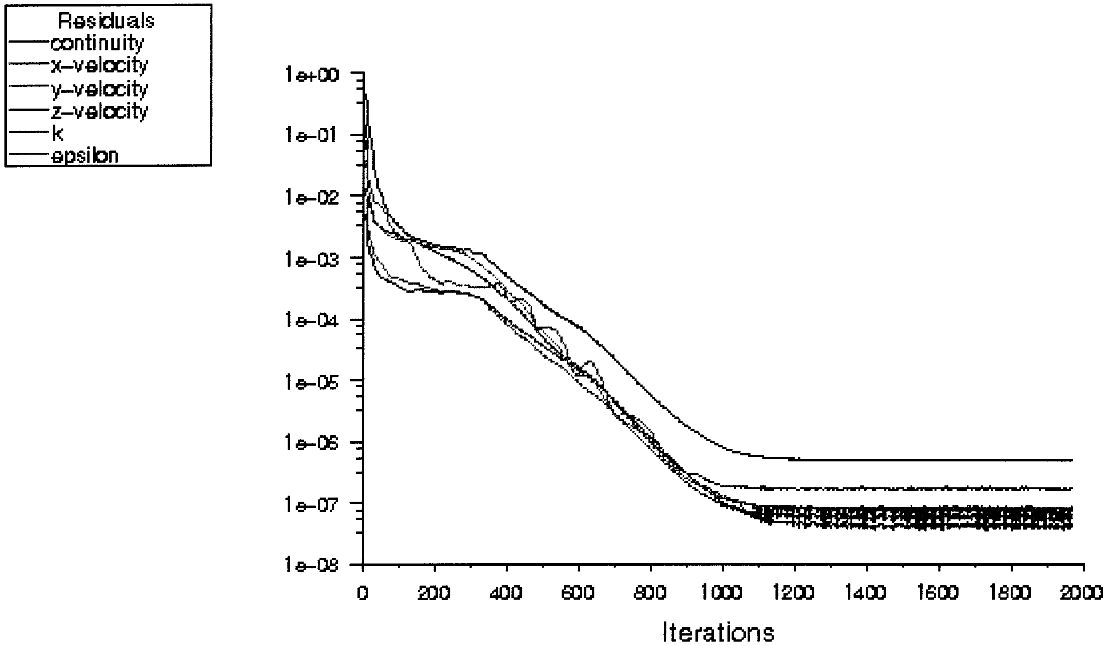
Appendix_3



Velocity Vectors Colored By Velocity Magnitude (m/s)

Dec 19, 2001
FLUENT 5.4 (3d, segregated, ke)

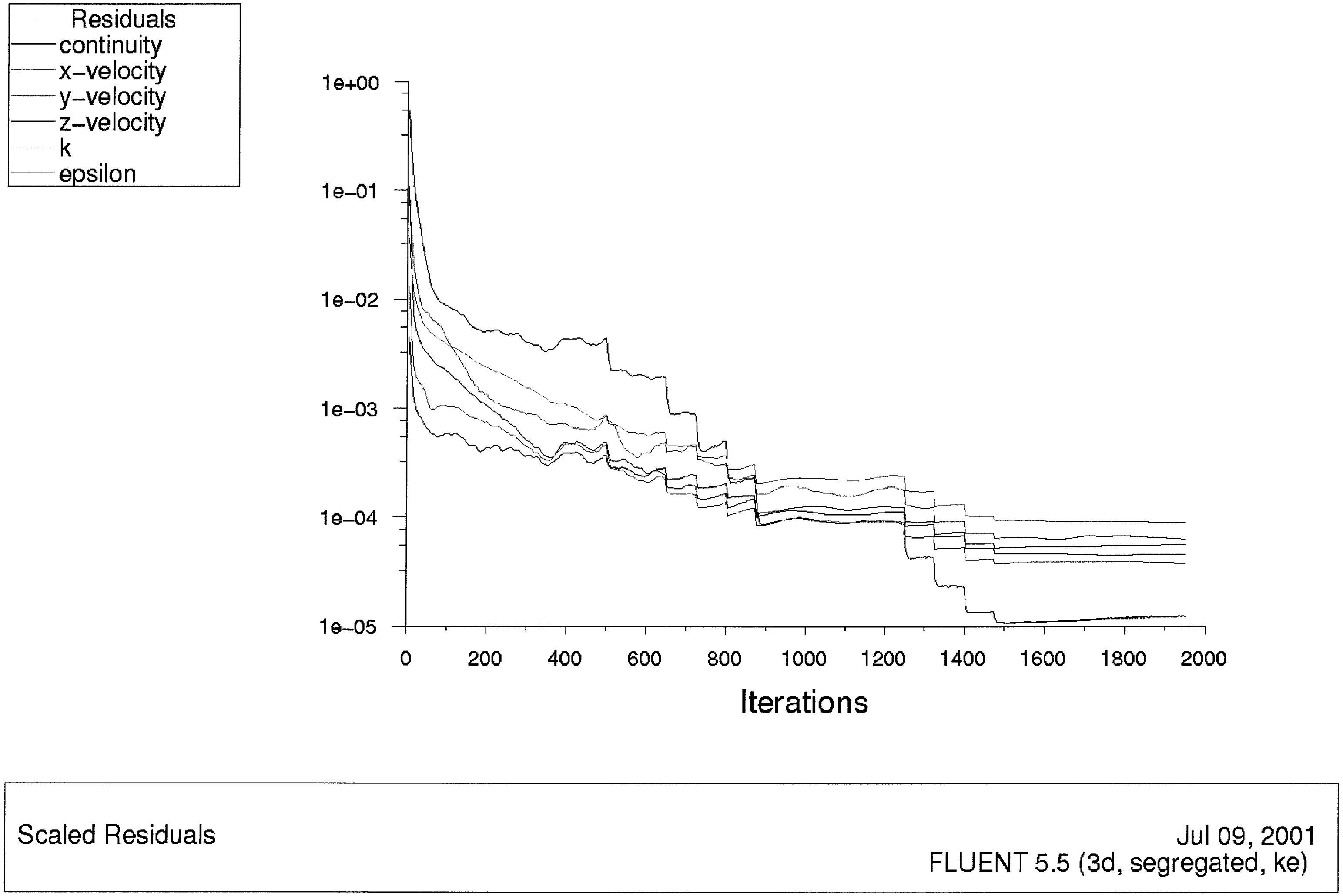
Inlets 6 m^3 , second order scheme by mix pipe 2.



Scaled Residuals

Sep 27, 2001
FLUENT 5.5 (3d, segregated, ke)

Appendix_3



Residuals for the 6 m^3 , second order scheme.