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Evaluation of the Snowfluent® Process for Big Sky Country Water and Sewer District No. 363 Big Sky, Montana

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TABLE OF CONTENTS

Executive Summary

The purpose of this study was to evaluate the effectiveness of Delta Engineering's Snowfluent® technology at the Big Sky County Water & Sewer District. This Atomizing Freeze Crystallization (AFC™) technology will allow the District to process and dispose of wastewater during the busy winter months. This will minimize the storage requirements for wastewater during the winter months and the land required to irrigate it during the summer.

Approximately 600,000 gallons of wastewater were processed using the Mobile Snowfluent® Wastewater Treatment Plant during the month of March, 1997. The snow was deposited on lined and unlined storage areas. Samples of raw sewage, fresh snow, aged snow and meltwater were secured at appropriate times throughout the study period.

The performance of the Snowfluent® treatment on key environmental contaminants such as Fecal Coliforms and Ammonia was excellent, with removal rates of 100% and 98.4% respectively. The BOD_5 and Phosphorous removals at 75% and 32-45% were lower than what is typically achieved with the Snowfluent® technology. However, sampling difficulties and air born contamination appear to be the most likely causes for this decrease in the expected performance. Also, the planned disposal method of exfiltration to the soils will handle any BOD_5 and Phosphorous that is not precipitated by the Snowfluent® process.

Based on the results of this study and the performance of Snowfluent® at other sites in full scale operation, Snowfluent® would be a suitable treatment option in the winter time for the Big Sky County Sewer & Water District.

1.0 Introduction

Ice is a solid that consists of a crystalline arrangement of water molecules. Because of its highly organized structure, ice cannot accommodate other atoms or molecules without severe local strain. An ice crystal grows by adding water molecules to its structure at the crystal boundaries. If a growing crystal comes in contact with other atoms or impurities it rejects them in favor of water molecules.

Atomizing Freeze Crystallization employs many natural biological and chemical processes inherent in freezing to eliminate various wastewater impurities. Through rapid crystallization, the process kills bacteria, precipitates dissolved contaminants, and separates suspended solids (D. Huber and G. Palmateer 1985).

The application of the freeze crystallization process for the concentration of food products, wastewater and desalination of brackish water has been investigated for many years. Freeze concentration and separation of salts is possible when a solution of inorganic salts are cooled. The growing ice crystals incorporate molecules of water and rejects salts or other impurities. Contaminants are concentrated in the remaining solution, provided that the solubility limits are not exceeded. In this process the temperature is usually below eutectic point and only a portion of the solution volume is solidified.

In the Atomizing Freeze Crystallization process, the separation occurs differently. It is based on one of the most interesting phenomenon occurring in the snowpack - snow metamorphism. Based on this phenomenon, Delta Engineering has developed the Snowfluent® technology, which is successfully used for wastewater treatment in cold regions.

2.0 Selected Aspects of the Snowfluent® Process

This section briefly explains the physical, chemical and biological nature of the Snowfluent® process. A schematic of the process is shown in Figure 1.

Chemical action: A number of different inter-related reactions occur throughout all phases of the Snowfluent® process. These phases have been divided into five steps for the purpose of clarity.

Step 1: Atomization and Projection. At this point, the untreated wastewater is delivered at high pressure to the atomizing nozzles. The fine droplets are projected into the atmosphere where it undergoes a process similar to that associated with spray irrigation. The concentration of ammonia is reduced by about 5% to 8%, and almost all hydrogen sulphide (H_2S) is removed by the stripping action. Also, up to 10% of the water will be lost due to the evaporative requirement of the heat transfer process, depending upon ambient conditions. This action is relatively short lived as the droplets rapidly freeze.

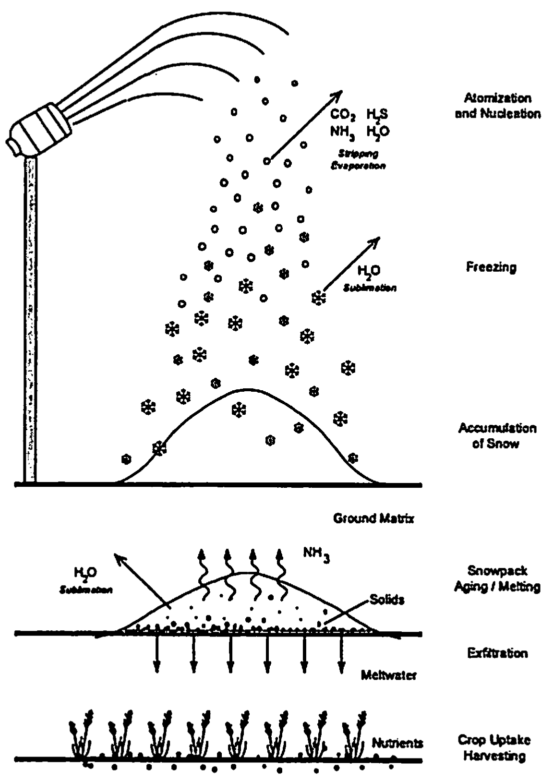


FIGURE 1 - The Snowfluent® Process (Exfiltration Option)

Step 2: Freezing. As the droplets freeze, a number of instantaneous reactions occur. First, because the droplets freeze from the outside-in, a layer of ice will be formed on the surface of the droplets. This enveloping layer will halt the evaporation of water as well as the stripping of ammonia and other hydride gases. As each frozen droplet continues to fall, up to 20% of its mass can be lost through sublimation, depending on the meteorological conditions and the time of trajectory.

The freezing of the effluent has been shown to cause the following:
First, significant quantities of CO_2 come out of solution and are stripped away, which causes hydrogen ions to decrease.

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+ \quad [1]$$

The decreasing levels of CO_2 and H^+ ions are reflected by a significant jump in the pH level of from 1.5 to 2.5 points.

In order to volatilize ammonia from wastewater, the ammonia must be in the molecular form NH_3 rather than the ammonia ion (NH_4^+) form. The equilibrium equation for ammonia in water is represented by:

$$NH_4^+ \leftrightarrow NH_3 + H^+ \quad [2]$$

In typical wastewater effluent, characterized by an average pH of 7, almost all ammonia is present in the ion (NH_4^+) form.

Raising the wastewater pH level to about 8.5 - 9.5, after Atomizing Freeze Crystallization, decreases percentage of ammonium ions. More nitrogen is present in the form of ammonia NH_3 (Fig. 2). This creates favorable conditions for volatilization of ammonia.

Despite the fact that thorough conversion of ammonium ion (NH_4^+) to the molecular form is completed at pH values ~11.5, it is likely that processes occurring in the snowpack such as repeated melting and re-freezing, as well as the long storage time and the extended melting period, can improve the rate of volatilization of ammonia nitrogen. As reported earlier (Huber, D and Palmateer, G 1985), after converting effluent to snow and storing it for 49 days, the reduction of ammonia was about 90 % at a pH of 9.73.

If an insignificant amount of ammonia remains in ionic form, it undergoes biochemical reactions during melting and infiltration processes and can be removed, as a nutrient, by assimilation, nitrification and denitrification. Microbes present in the soil will assimilate ammonia nitrogen and incorporate it into their cell mass.
In the soil, the removal of nitrogen can be accomplished in two steps. In the first step - nitrification, the oxygen demand of ammonia is reduced by converting it into nitrate. In this step, nitrogen is not removed, but has only changed its form. In the second step-denitrification, nitrate is converted into a gaseous form and volatilized.

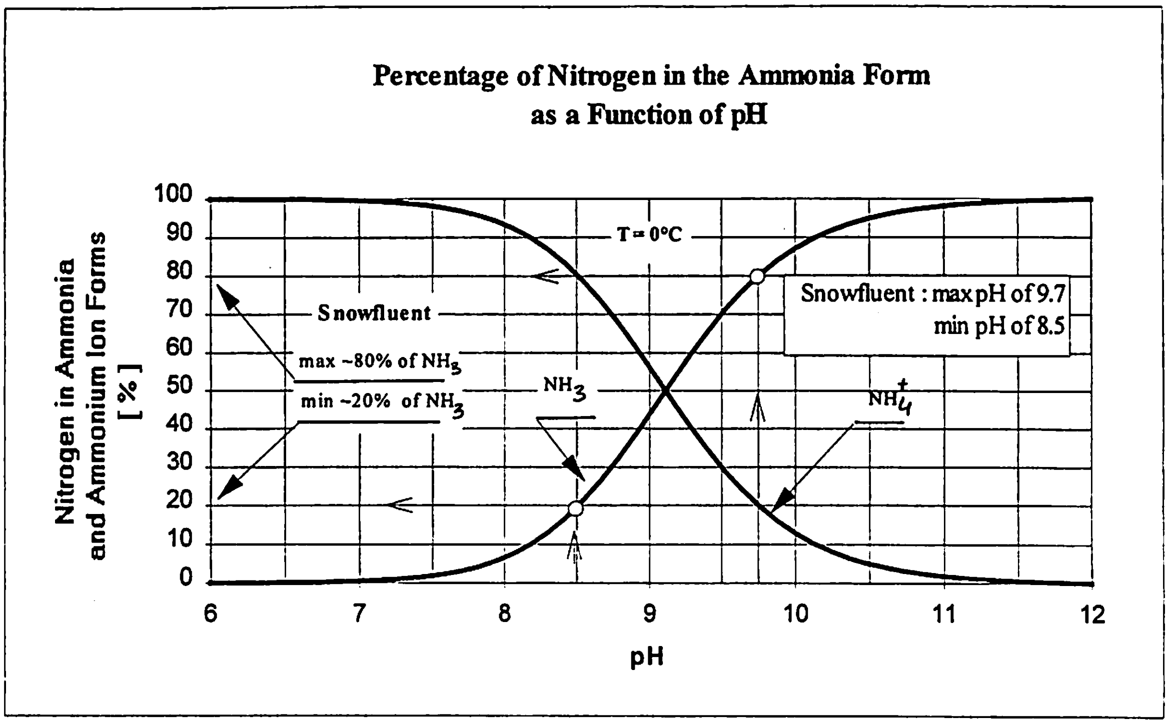


Figure 2. Percentage of Nitrogen in the Ammonia form as a function of pH

The freezing of the wastewater droplets also causes other dissolved compounds such as calcium, magnesium, chlorides, and sulphates etc., to precipitate. This is due to the increasing concentration of the dissolved salts in the liquid fraction as ice formation progresses, and the reduction of temperature. These compounds will also be trapped at the centre of the globules of ice, and will not re-dissolve without the addition of sufficient heat and water.

By the same mechanism, dissolved phosphorus will also be forced out of solution as a phosphate salt. Although the phosphate ions will prefer to combine with the more active ammonium ion to form highly soluble ammonium phosphate, the reduced availability of ammonium due to conversion to NH_3, will require it to seek out other cations. In the presence of sufficient hardness, calcium and phosphate will precipitate. This reaction is a key element of the process, as the conversion of phosphorus into an insoluble form will prevent it from re-dissolving into the melted snow under any conditions. This behaviour is fundamental to the ultimate removal of phosphorus from the treated wastewater stream. It should be understood however, that this action is not instantaneous but occurs gradually as the snow pack ages and NH_3 slowly volatilizes.

Step 3: Aging of snowpack. It is known that when a water droplet freezes while airborne, intracrystal forces cause a phenomenon similar to 'zone refining', which moves any dissolved or suspended solid contaminants into the centre of the water droplet as ice forms a solid crust on the droplet surface and freezes progressively in toward the centre.

When the snow layer is subjected to a consistent negative temperature for a long period of time, the top surface of the lower(warmer) snow grain sublimates and then the vapor migrates upward by diffusion. This movement is caused by a gradient of saturated water vapor pressure, according to a temperature distribution in the snow porous medium. When the molecules of water vapor reach the bottom surface of the upper (colder) snow grain, the condensation takes place and the so called hoar crystal is created. Transfer of mass in the form of pure water vapor causes concentration of impurities at the grains surface. This phenomenon is energetically favorable because impurities located on the ice grain surface or as disordered grain boundaries cause a less strain than if they are located within the ice matrix itself. There is an exclusion of ions and solid impurities from snow grain interiors to their surface. Not all ions are excluded in the same percentage. Some ions like chloride (Cl^-) or Ammonium (NH_4^+) are more easily incorporated into the ice structure than others.

As the snowpack is formed, the frozen particles have entrapped within them a number of different constituents. These ice particles will immediately begin to undergo the metamorphosis discussed above. This ultimately produces what is commonly known as "corn" or "sugar" snow. The effect of this metamorphosis on wastewater treatment is that it allows the entrapped solids and gases to be released into the interstitial spaces between ice particles. The solids have been observed to slowly gravitate to the bottom of the snowpack, while gases migrate upward to be eventually released to the atmosphere.

As the crystal metamorphosis is an on-going process, so are the chemical processes. With the continued aging of the snowpack, the pH of the snow remains high and the conversion processes continue until virtually all NH_4^+ has been converted to NH_3 and volatilized. The phosphorus is thus rendered insoluble as a calcium or magnesium salt.

Step 4: Melting of snowpack.

As the ambient temperatures increase, the internal temperature of the snowpack will begin to increase. When this core temperature reaches 0°C, melting begins and another process known as “ionic pulse” takes place. At the beginning of the melting season, the metamorphism of the snow grain is enhanced by both greater frequency and fluctuations of temperature extremes. Preferential elution of impurities also occurs during this time. This also results from exclusion of impurities during the snow grain metamorphosis. The extent of this exclusion depends upon the chemical species or ions. This process is similar to the exclusion of ions from freezing brackish water, where less soluble salts are more efficiently excluded than soluble ones. The more efficiently excluded ions are more highly enriched on the snow grain surface and appear sooner and in higher concentrations in the elution water.

The first rain or meltwater washes the snow-pack in the same way a cake gets washed in a vacuum filtration process. At this time the structure of the hoar crystal is fully developed and the impurities are easily washed from the grain surface.

The movement of impurities within the snow-pack may also be the result from thaw/freeze cycles during the melting season. Series of these thaw/freeze cycles occur after the initiation of the snow-pack runoff and increase the concentration of impurities in the first meltwater. As metamorphism takes place, the surface area of the snow medium decreases and porosity increases. The hydraulic conductivity increases as a result of this. Once the melt or rain water infiltration wets the snow, the process driving the crystal growth accelerates. The rate at which the impurities are removed depends upon the atmospheric conditions under which the snow was deposited as well as the degree and type of metamorphism the snow-pack has experienced. In the case of man made snow, the mean diameter of atomized water and moisture of snow has a significant and direct influence on the metamorphism process.

The freeze/thaw cycles remove the impurities from the upper portion of the snow-pack and concentrates them in the lower portion, where they can easily be removed with the early water runoff. At the lower flow rates, molecular diffusion is also important. These impurities get into the moving water by diffusing away from the snow-pack pores.

The combination of freeze/thaw cycles followed by rain could remove the largest quantity of impurities with minimum amount of meltwater. Different grain scale distribution may have contributed to the elution rates. When the snow is wet the ice crystals form clusters that can freeze into polycrystalline particles. This formation dramatically increases the porosity of the snow-pack causing an increase in hydraulic conductivity. This results in an increase in the infiltration flow rate.

When moving downward in the snow-pack, the first melt or rain water elutes ions from the grain surface. Therefore, the concentration of solutes in the initial 20-30% of meltwater contains 50-80% of the total solutes in the snow-pack. Even in natural snow, the first 20% of meltwater is enriched with the soluble impurities. Although the average concentration of soluble impurities in natural snow is generally very low, preferential elution of ions within initial meltwater occurs.

The meltwater will then be released under controlled conditions following either of two separate options, as determined by local conditions. The water can either be allowed to infiltrate the soils beneath the snowpack, or be collected in a contained impermeable area and subsequently decanted and discharged into a designated, approved receiving body of water.

During the Atomizing Freeze Crystallization process, as well as during the aging of snow, growing ice crystals can compress, agglomerate and dehydrate solid particles. This process is driven by natural forces, without any addition of chemicals.
Our present knowledge of freeze/thaw processes, as well as the observation of physical properties of the snow-pack during the metamorphism, allow us to hypothesize that series of freeze/thaw cycles that occur during the metamorphism of snow and during the melting of snow-pack, reject solid particles at the surface of the snow grains and

agglomerate them. Moreover, it is believed that some elements and microorganisms are absorbed by solid particles and separate from the water.

Step 5a: Exfiltration option. If it has been determined by hydrogeological analysis that the soils below the snow deposit have adequate permeability and absorption capacity, the meltwater will be allowed to infiltrate the soils. The insulating properties of the snowpack will have prevented virtually any frost penetration or retention in the ground matrix. This will allow the soils in the deposit area to accept the meltwater with no surface runoff.

As the meltwater passes into the soils, the precipitated contaminants will be in the form of a nutrient residue and will be trapped at the surface of the ground matrix. These nutrients are available to vegetation such as forage crops, which can later be harvested. Crop harvest accommodates the process, as it removes most of the nutrients from the area. Table 1 lists a number of selected crops and their associated nutrient uptake rates. Crops are selected for their hardiness, uptake rates, and their early growth rates.

TABLE 1 - Nutrient uptake rates for selected crops (kg/ha - yr.)[2]

	Nitrogen	Phosphorus	Potassium
Alfalfa[a]	225 - 540	22 - 35	175 - 225
Bromegrass	130 - 225	40 - 55	245
Coastal bermuda-grass	400 - 675	35 - 45	225
Kentucky bluegrass	200 - 270	45	200
Quackgrass	235 - 280	30 - 45	275
Reed canary-grass	335 - 450	40 - 45	315
Rye-grass	200 - 280	60 - 85	270 - 325
Sweet clover[a]	175	20	100
Tall fescue	150 - 325	30	300
Orchard-grass	250 - 350	20 - 50	225 - 315
Barley	125	15	20
Corn	175 - 200	20 - 30	110
Cotton	75 - 110	15	40
Grain sorghum	135	15	70
Potatoes	230	20	245 - 325
Soybeans[a]	250	10 - 20	30 - 55
Wheat	160	15	20 - 45

a. Legumes will also take nitrogen from the atmosphere.

The exfiltration option is ideal in applications where no direct discharge of wastewater effluent into a receiving body of water is desired, or where a viable receiving body of water is unavailable.

Step 5b: Collection and decanting. If it has been determined that the soils at the snow deposit site are unsuitable for absorption of meltwater, the decanting option may be used. In this scenario, the deposit area is designed in a fashion to contain the meltwater. Precipitated contaminants are allowed to settle to the bottom of the containment area. Meltwater is then discharged from the surface via decantation. After several years, the accumulated residue can be collected by standard means, and used as a crop fertilizer, etc..

3.0 Background

Sewage treatment for small communities, seasonal resort development and small industries is an expensive undertaking throughout the Northern United States and Canada. One of the least expensive methods of treating sewage or waste is the facultative lagoon system. While such lagoons provide adequate and flexible waste treatment for many municipalities, major disadvantages of the lagoons in some situations are the large amount of land required and their poor removal efficiencies during the winter months. The land requirement varies with serviced population and discharge mode. Storage requirements normally vary from four to twelve months, which can result in the removal of excessive acreage of land from production or tourism development.

Wastewater treatment options were being considered for Big Sky's Mountain Village as part of the Long Range Facility Plan. A scenario being considered involves the majority of wastewater being stored over the winter for disposal by irrigation on a golf course in the summer. The costs and land requirements associated with spray irrigation make a solution conducive to reducing both of these restrictions attractive. The Snowfluent® process could accomplish both cost reduction and land requirement reductions by reducing winter storage requirements, resulting in less wastewater treated by spray irrigation annually.

The following report contains results and discussion of a testing program carried out at the Big Sky Water & Sewer facility at Big Sky Montana. The project involved treating the ski resort's wastewater with Snowfluent® - Atomizing Freeze Crystallization (**AFC™**) technology. The objective of the program was to verify previous performance data of the Snowfluent® system in order to evaluate its potential to be incorporated into the Long Range Facility plan. Snowfluent® would offer the possibility of reducing winter storage requirements. The report includes a description of the field experiment along with a summary of results and discussion.

Delta Engineering has noted high levels of treatment in series of tests done at municipal fluid wastes with very minimal pretreatment i.e. settling of solids. The first permanent Snowfluent® plant located in Maine has completed its 3rd year of operation. A Second permanent plant, in Canada, was opened in Westport in 1996. Efficiency of treatment at these plants were reported as very high. Two additional plants in Mars Hill, Maine and Swift Current, Saskatchewan will start up in the fall of 1997.

If the test data can be verified, the Big Sky Country Water & Sewer District would consider locating a Snowfluent® process at the Mountain Village to treat winter flows. In addition to the system at the Mountain Village, the district would consider locating a system in the vicinity of Meadow Village.

Snowfluent® in the Meadow Village area would utilize effluent from the advanced treatment plant. Again the use of Snowfluent® would reduce storage requirements and would provide an additional disposal method.

4.0 Project Objectives

Snowfluent® is a natural process which is strictly correlated to environmental conditions. Parameters such as weather conditions and geological properties of the soil influence the Snowfluent® process in its design and efficiency.

Each site has different configurations, soil conditions, weather conditions and different characteristics of wastewater. Therefore, each plant needs to be designed separately for these conditions. The climate in Big Sky differs from that of other plants previously tested. The objective of this trial demonstration was to determine the over all effectiveness of the temporary Snowfluent® facility in Big Sky.

Other aspects of the operation that were assessed are:

- Assessment of treatment efficiency
- Environmental impacts due to snow deposition

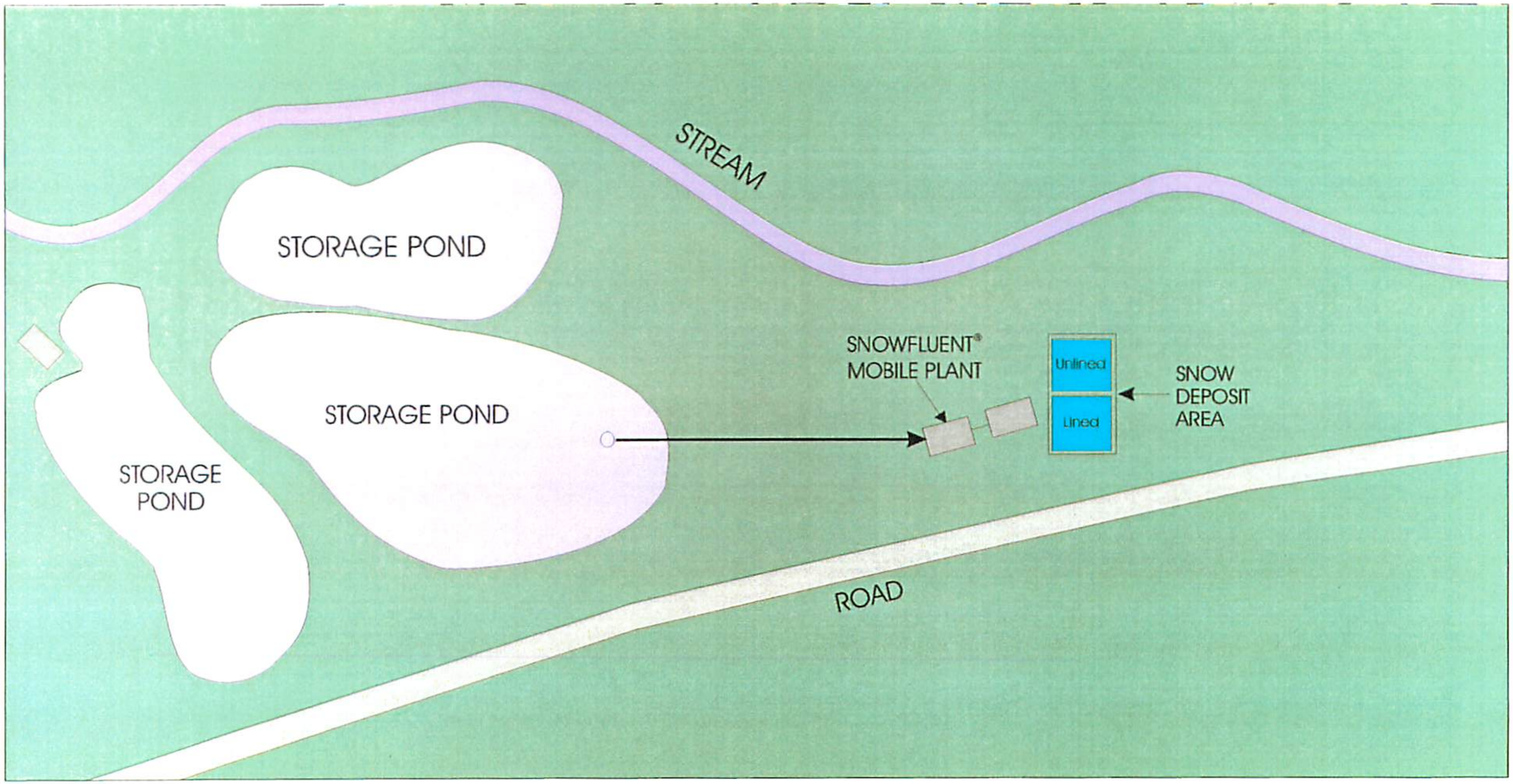


Fig. 3: Snowfluent® Field Experiment - Big Sky, Montana 1997

5.0 Technical Approach of Experiment

Site Description

The test area, shown on Fig. 3 , consisted of two side by side sites. Each site was approximately 100 feet by 100 feet. Both plots were cleared of natural snow . One site was lined with a 10 mil geomembrane to contain the meltwater.

An open area in the containment berm was provided to collect and drain the meltwater from the lined site. The construction of the collection site is presented in Appendix A.

The site was located up-gradient of the runoff control system constructed by Van Dyke Construction as part of their construction. Five shallow groundwater monitoring wells were installed around the ponds. Two monitoring wells were located down-gradient of the collection sites. The monitoring wells consisted of 2-inch diameter perforated PVC pipe.

Fig. 4. Atomizing Freeze Crystallization Research Facility - Mobile Unit

Description of the pilot plant

The pilot plant consists essentially of a high pressure pumping system and compressed air system mounted inside two trailers along with a diesel generator. This mobile plant is presented in Figure 4.

The high pressure pumping system includes a small submersible pump which feeds a 40 HP high head horizontal booster pump. Both pumps are electrically driven, and the discharge pressure is controlled by a manually operated pressure control valve.
This system is used to pump wastewater under high pressure through a series of hoses to a portable tower or tripod unit.

Compressed air is delivered at about 700 kPa (100psi) with the high pressure water to a specialized Delta snowmaking nozzle. At the nozzle, water and compressed air are projected into the cold atmosphere in an atomized form such that the water droplets freeze rapidly and completely.

A control system helps regulate the rate of wastewater flow depending on local climatic conditions and system capacities.

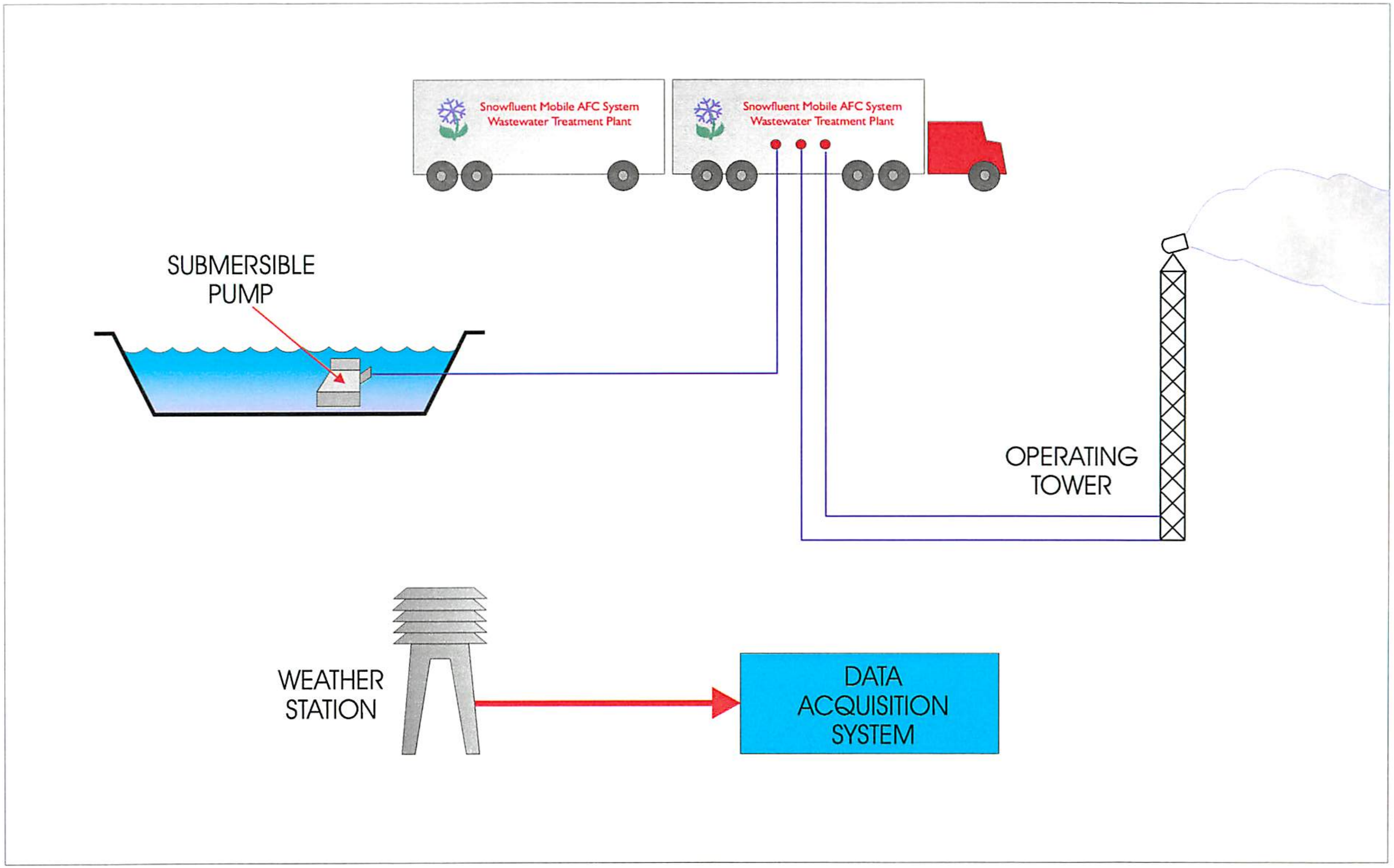


Fig. 5: Schematic of AFC - Snowfluent® Mobile Plant - Big Sky, Montana 1997

6.0 Monitoring Program

The sampling program was designed to achieve two goals. The first goal was to assess the efficiency of the treatment process, and the second was to assess impacts on the environment from the treatment process.

The applied water, fresh snow, aged snow, meltwater and groundwater were to be sampled and analyzed , on a regular basis, for the following parameters: fecal coliforms, Total Suspended Solids, BOD_5, Orthophosphate, Total Phosphorous, Nitrate & Nitrite, Ammonia, Total Kjeldahl Nitrogen, Alkalinity, Conductivity, and Sulfate.

The guidelines for sampling were developed and provided to draw attention to items of specific interest to the Snowfluent® process.

The major elements planned for monitoring in a Big Sky Snowfluent® test were:

- containment lagoon effluent
- fresh and aged snow
- meltwater
- groundwater

The goals of the pilot plant test at Big Sky, Montana were defined as follows:

- Determine the snowmelt concentrations for BOD_5, TKN, Ammonia NH_3 and NH_4^+ , NO_3 and NO_2, TP, Fecal Coliforms, pH, TSS, Sulfate as well as Conductivity and Alkalinity
- Determine any impacts of the snowmelt to the groundwater
- Determine the run-off concentrations if a surface runoff system is utilized
- Provide enough background data to evaluate the feasibility of constructing a Snowfluent® system at either the Mountain Village, Meadow Village or both locations.

The monitoring program for the Snowfluent® field experiment at Big Sky was prepared. This program is briefly summarized in Table 2.

Lagoon effluent and fresh snow usually are sampled every second day during the snow production. The suggestion of aged snow sampling weekly was based on previous experience with Snowfluent® experiments.

During the initial 2 weeks of melting conditions, it was proposed to sample the meltwater from the lined pond every other day. Duplicate samples should be collected and analyzed for the same parameters listed above.
After the first 2 weeks of sampling , the sampling program could be reduced to one per week.

Table 2

Test Program				
Sampling Element	**Sampling Location**	**Sampling Time (Frequency)**	**Type of Sample**	**Parameter**
Lagoon Effluent	Lagoon or Snowfluent® Piping System	During the production (Every second day)	Composite	TSS, BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH Fecal Coliforms
"Fresh" Snow	Snowpack	During the production (Every second day)	Grab or Composite	TSS, BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH Fecal Coliforms
"Aged" Snow	Snowpack	First Two Weeks (Every second day)	Grab or Composite	TSS, BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH Fecal Coliforms
"Aged" Snow	Snowpack	To the end of melting season (weekly)	Grab or Composite	TSS, BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH Fecal Coliforms
Meltwater	Snow Disposal Area	During the melting (Every second day)	Composite	TSS, BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH Fecal Coliforms
Groundwater	Snow Disposal Area	During the melting & after experiment (3 times)	Grab	BOD5, PO4 , TP, NO3 & NO2, NH3, TKN, SO4 Alkalinity, Conductivity, pH

7.0 Field Experiment - Procedures

The field experiment at Big Sky began at the beginning of March 1997 and finished at the end of May, when all the snow had melted. During the production of the snow, the temperatures did not allow the test to proceed in a continuous form. Most temperatures below 0 °C occurred during the night. Therefore, the site was illuminated for operation during non-daylight hours.

The snowmaking program was run intermittently between March 5 - March 17, 1997. Snow was made typically at night, when the temperatures were cold enough to process.

A temporary Snowfluent® installation (mobile unit) was set up at a site close to the aeration pond. The wastewater was pumped to the atomizing nozzles at a rate of approximately 80 gpm.

Significant quantities of wastewater from the Big Sky treatment lagoons were converted into snow. It was estimated that about 2300 m^3 of wastewater was converted to about 4200 m^3 of man made snow. Approximately 2100 m^3 were placed in the lined containment area and 2100 m^3 were placed on the unlined containment area.

The meltwater was accepted to infiltrate into the ground. This allowed impact on the groundwater to be evaluated. No runoff to the surface streams occurred from the snowmaking test site.

Three shallow monitoring wells were installed inside the unlined plot and two within the lined plot. A shallow collection ditch was constructed at the plots periphery.

Qualitative tests of the wastewater, converted snow, and meltwater were performed by Big Sky Country Water & Sewer District.

The testing of snow began on the first day of the test on March 5, 1997 and finished on March 16, 1997.

Analyses of Fresh Snow and Raw Wastewater

Fresh snow was sampled the morning after the previous nights' production and was collected off the top of the pile. A sterilized plastic scoop was used to transfer the snow into 500 ml, 2000 ml and into bacteriological sample bottles. All samples were transported to the lab in a cooler promptly after being taken.

The samples of wastewater were taken on the same days. This allowed a direct comparison of applied water and snow on the pile. Processed wastewater was sampled from the storage pond within 10 feet of the intake hose for the submersible pump. Samples were drawn through a hole bored in the ice.

Analyses of Aged Snowpack

The aged snow samples were obtained from the testing pit on the lined section of the plot. Aged Snow was collected off the bottom 1- 2 feet of the snowpack and was obtained by digging into the snow pile to reach a fresh wall of snow. The photo of the sampled area is presented on Fig. 6. On Fig. 7, the sample pit is shown. The aged snow was sampled approximately every second day and then generally on a weekly basis until the final snowmelt.

Meltwater

In the 3rd phase of Snowfluent® experiment at Big Sky, the meltwater was sampled and analyzed. During the melting phase of the project, the samples were collected off the lined portion of the test site. The testing of the meltwater began when the meltwater was observed in the lined containment pond.

Meltwater was intended to be collected out of a shallow discharge ditch, which was fed by meltwater off the liner. The reason for this was to allow time for proper separation of the precipitated contaminants from the meltwater. The liner posed a problem in that the meltwater would collect in pools caused by the uneven ground suface and would not readily drain down the shallow ditch that was constructed for that purpose.
It was found by engineering personnel at Big Sky, that if the liner was pulled up prior to testing and close to the pile to form a pool where the water could collect, the fresh sample could then be drawn. Care was taken not to scrape the liner while the sample was collected. Samples were collected 2-3 times weekly during late April and throughout most of May.

All of the samples were transported to the lab within hours in a cooler. The last snow melt samples were taken on Friday, May 23. By Monday, May 26 the pile of snow was almost gone. Very little remained to sample and it was extremely dirty with dust and other debris resulting from the start of storage pond construction.

Groundwater

It was planned to collect the groundwater samples from the monitoring wells on a weekly basis during snowmelt. However, the 5 shallow groundwater monitoring wells that were installed never did produce enough water to sample. The only well that did have water in it was the monitoring well in the middle of the unlined plot. But, there was not enough for proper sampling and analysis.

Fig. 6 Snowfluent® Deposit Site. Field Experiment, Big Sky, Montana 1997

Fig. 7, Aged snow sample pit.

8.0 Results

The quality of snow produced during the field experiment was excellent. The wastewater droplets froze rapidly and thoroughly. The consistency of snow approached that of sugar in the size of granules and its ability to be poured like sugar. Odors were minimal. No complaints regarding odors or noise were received due to the operation of the mobile plant.

Raw Wastewater and Fresh Snow

Table 3 contains data from the raw wastewater and the fresh snow.

The bacterial level of *Fecal Coliforms* in the "fresh" snow were typically undetectable. The rapid freezing of small droplets create favorable conditions for killing bacteria and other microorganisms.

Total Suspended Solids (TSS) increased from 21.5 to 43 mg/l (median value). This instantaneous increases in suspended solids is the result of insoluble carbonates forming during the freezing process.

The typical BOD_5 in the lagoon wastewater was 33 mg/l during the snow production. At the same time the median value of BOD_5 in "fresh" snow was 34 mg/l. Similar results were noted previously in other Snowfluent® operations. Since no separation has occurred yet, significant reduction of BOD_5 is not usually expected at this stage of the process.

Total phosphorous remains at the same level, as expected, in the wastewater and in the fresh snow: 7.1 and 7.2 mg/l respectively. Orthophosphate levels in the fresh snow decreased to the level of 50% of that in the wastewater and were reported as a median value of 2.1 mg/l. This indicates the formation of calcium phosphate particulate during freezing.

The pH in the lagoon wastewater ranged from 7.3 to 7.8 during the tests. The levels in the snow were typically 9.1 to 9.8. This increase in pH is a result of the removal of carbon dioxide during the atomizing and freezing process and is typical for wastewater after Atomizing Freeze Crystallization.

About 50% of ammonia as nitrogen was released during the snowmaking. The median value of ammonia in the lagoon wastewater was 56 mg/l. In fresh snow this value was reduced to the median value of 23.5 mg/l. This phenomenon can be explained by the fact that raising the wastewater pH level to about 9.1 , after atomization, decreases the percentage of ammonium ions. Thus, more nitrogen was present in the form of ammonia NH_3 and more ammonia could be volatilized during the snow production.

The values of TKN were noted to be lower than the ammonia levels. This is in error because TKN is the total of NH_3 - N and organic nitrogen and therefore can not be lower.

Table 3

Snowfluent® Field experiment - Big Sky 1997

Phase I - Chemical and Bacteriological Analyses of Wastewater and Fresh Snow

	FECAL COLIFORMS col/100 ml	TOTAL SUSPENDED SOLIDS mg/l	BOD_5 mg/l	ORTHOPHOSPHATE AS PHOSPHORUS mg/l	TOTAL PHOSPHORUS mg/l	NITRATE & NITRITE AS NITROGEN mg/l	pH	AMMONIA AS NITROGEN mg/l	TOTAL KJELDAHL NITROGEN mg/l	ALKALINITY mg/l	CONDUCTIVITY umhos/cm	SULFATE mg/l
Wastewater												
05-Mar	13,000	22	37	4.40	7.8	0.34	7.5	40	7.1	270	690	26
07-Mar	9,500	30	36	4.30	7.4	ND	7.3	56	18	270	710	39
09-Mar	6,400	21	31	4.10	2.5	ND	7.5	56	27	270	690	29
11-Mar	6,200	26	28	4.90	6.7	ND	7.8	57	44	260	650	27
13-Mar	7,400	8	34	4.60	7.4	ND	7.5	60	22	260	670	26
16-Mar	500	17	25	3.70	6.4	0.06	7.6	25	13	160	380	17
average	7166.7	20.7	31.8	4.3	6.4	0.07	7.5	49.0	21.9	248.3	631.7	27.3
median	6900.0	21.5	32.5	4.4	7.1	0.00	7.5	56.0	20.0	265.0	680.0	26.5
Snowpack "Fresh Snow"												
05-Mar	12	37	33	2.20	7.1	ND	9.1	28	11	260	600	19
07-Mar	ND	38	27	0.70	7.3	0.1	9.5	19	14	210	520	21
09-Mar	ND	48	35	3.80	8.2	ND	9.1	31	16	240	540	24
11-Mar	ND	100	7	0.42	3.8	0.11	9.8	4.4	5.4	100	150	ND
13-Mar	ND	36	39	3.80	6.4	ND	9	53	28	260	600	25
16-Mar	ND	88	38	2.00	7.2	ND	9.1	7.2	8.1	69	140	ND
average	2.0	57.8	30.0	2.1	6.7	0.0	9.3	23.8	13.7	190.0	425.0	14.8
median	0.0	43.0	34.0	2.1	7.2	0.0	9.1	23.5	12.5	225.0	530.0	20.0

This inconsistency could be the result of the laboratory not getting full digestion on the TKN values.

Decreasing levels of Alkalinity and Conductivity are the result of insoluble salts forming during the freezing process.

Nitrates and nitrites in the raw wastewater, as well as in the fresh snow were undetectable or at very low levels.

Aged Snow

Table 4 contains data from the chemical and bacteriological analyses of the aged snow. This data is also presented in graphical form in Appendix B_1.

The Fecal Coliforms continued to remain at non detectable levels for all but two of the aged snow samples.

Up to the beginning of April, the concentrations of ammonia in the snowpack were still at a similar level to the "fresh snow". After April 16th, the concentration of ammonia in the snow significantly decreased, to a level of 0.88 mg/l at the end of melting season in May. At the same time, some oxidation of nitrogen was noted, as shown by nominal increases in nitrate and nitrite levels. It should be noted that these levels of nitrate and nitrite at < 0.05 mg/l are insignificantly small because the maximum contamination level for drinking water is 10 mg/l.

As the snowpack was aging, the total suspended solids were increasing. This can be explained by the fact that rejected solid particles from the ice crystals were slowly eluted by infiltration meltwater or rain.

The BOD_5 of the snow at the end of melting season was also lower than in the fresh snow. This phenomenon was also noted for such parameters as alkalinity, conductivity and sulfate. The reduction of these contaminants in the snow during the melting season is the result of metamorphism of snow, as well as snowpack "washing" by the meltwater and the rainwater. Precipitated salts are rejected by the growing ice crystal during the metamorphosis of the snowpack. These salts are moved down in the snowpack by both rainwater and meltwater. The change in the aged snow samples between April 2nd and April 16th are an excellent example of this washing of the snowpack.

The levels of orthophosphate and Total Phosphorus varied up and down during the aging process. The exact reason for this is currently unknown, but some results, such as the 9.8 mg/l for orthophosphate on April 16th, with a Total Phosphorous only 9.3 mg/l are suspect. Orthophosphates are part of Total Phosphorus and thus must necessarily be less than or no greater than the value of total P. Both of these results were significantly higher than the results on samples taken before and after this date.

Table 4

Snowfluent® Field experiment - Big Sky 1997

Phase II, Chemical and Bacteriological Analyses of Aged Snowpack

Snowpack - "Aged"	FECAL COLIFORMS	TOTAL SUSPENDED SOLIDS	BOD_5	ORTHOPHOSPHATE AS PHOSPHORUS	TOTAL PHOSPHORUS	NITRATE & NITRITE AS NITROGEN	pH	AMMONIA AS NITROGEN	TOTAL KJELDAHL NITROGEN	ALKALINITY	CONDUCTIVITY	SULFATE
	col/100 ml	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	umhos/cm	mg/l
05-Mar-97	ND	44	34	1.9	6.6	ND	9.2	34	10.2	230	570	25
07-Mar-97	ND	42	44	1.6	7.7	ND	9.3	34	18	220	490	22
09-Mar-97	ND	21	51	2.7	7.5	ND	9.5	27	16	210	480	23
11-Mar-97	ND	42	32	2.2	8.9	ND	9.5	34	20	200	450	24
13-Mar-97	ND	18	50	2.9	4.5	ND	9.6	21	21	170	460	29
16-Mar-97	ND	37	17	3.2	8.1	ND	9.4	75	33	230	550	27
20-Mar-97	ND	48	35	3.70	6.7	ND	9.3	20	42	180	480	25
25-Mar-97	ND	72	33	2.60	4.3	ND	9.2	94	63	310	88	40
02-Apr-97	ND	90	66	2.10	4.0	0.04	8.9	17.54	28.1	220	610	25
16-Apr-97	94	75	29	9.80	9.3	0.05	9.3	7.4	13.12	80	120	ND
24-Apr-97	ND	90	10	3.00	6.3	0.01	8.7	3.07	4.57	85	130	ND
01-May-97	ND	78	5	0.99	5.5	0.01	9.3	1.38	3.08	62	99	ND
12-May-97	ND	63	12	1.90	3.4	0.02	9.5	0.88	2.9	60	70	ND
average	14.6	55.4	32.2	3.0	6.4	0.03	9.3	28.41	21.15	173.6	353.6	18.5
median	0.0	48.0	33.0	2.6	6.6	0.00	9.3	21.00	18.00	200.0	460.0	24.0

Meltwater

The chemical and bacteriological analyses of the meltwater are contained in Table 5. This data is also presented in a graphic form in Appendix B. Table 6 contains summary data on the Total Reductions achieved with Snowfluent®.

The Fecal Coliforms continued to remain very low and were typically non-detectable throughout the melting period. These results are an example of the disinfecting properties that are normally experienced with Snowfluent®.

Total Suspended Solids varied from four samples with 0 mg/l to the final sample at 84 mg/l. There are a couple of reasons for these variations. As discussed previously, the sampling technique that was necessary to obtain sufficient quantities of meltwater (raising the liner to pool the water) may have caused some settled material to be disturbed and as such be reintroduced to the sample. Also, there was significant airborne dust from nearby construction that was settling out at times on the snow deposit site and the adjacent pooled water.

The BOD_5 median value was 8.0 mg/l. While this represented a 75.4 % reduction from the raw water, Snowfluent® typically develops much lower levels (< 2 mg/l) of BOD_5 in the meltwater (See the attached results from Westport). As with the TSS, external factors and sampling may have contributed to the higher levels of BOD_5.

Orthophosphate and Total Phosphorous levels were reduced by between 32-45% respectively. Again, for the same reasons as above, this performance is not on par with other applications (See the attached results from Westport). However, since the intention is to infiltrate the meltwater into the soils, any phosphorous compounds that are not precipitated on the surface will be adsorbed by the top strata of the soils matrix.

The results on the nitrogen contaminants were outstanding, with a 98.4% reduction in ammonia and an 88% reduction in the TKN. The median ammonia level of 0.9 mg/l, while higher than what would be expected from a full scale operation, is still very acceptable for discharge. Due to the absence of bacteria and the cold temperatures, there was no nitrification of the ammonia, hence no increases in nitrate or nitrite - N were detected in the meltwater.

During the latter stages of the snowpack aging process, the alkalinity, conductivity and sulfate in the meltwater were also significantly reduced by 70%, 75% and 100% respectively. These are all indicative of the significant separation of contaminants that normally occurs with the Snowfluent® technology. In the case of normally soluble salts such as sulphates, chlorides etc., concentration effect causes precipitation and release of the heat of crystallization. Resolubilization does not occur unless the heat of solution is regained. This allows for an immediate separation of such salts from the water fraction by using the exfiltration effect of the soil matrix. Plants growing in this immediate area readily access these normally soluble salts. At Carrabassett Valley Sanitary District in

Table 5

Snowfluent® Field Experiment - Big Sky 1997

Phase III: Snowmelt - Chemical and Bacteriological Analyses

Snowmelt	FECAL COLIFORMS	TOTAL SUSPENDED SOLIDS	BOD_5	ORTHOPHOSPHATE AS PHOSPHORUS	TOTAL PHOSPHORUS	NITRATE & NITRITE AS NITROGEN	pH	AMMONIA AS NITROGEN	TOTAL KJELDAHL NITROGEN	ALKALINITY	CONDUCTIVITY	SULFATE
	col/100 ml	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	umhos/cm	mg/l
24-Apr-97	ND	28	7	2.4	4.2	0.04	7.7	0.78	1.31	50	140	ND
28-Apr-97	ND	0	11	3.4	4.3	0.04	8.1	4.25	5.65	90	210	ND
30-Apr-97	ND	8	1	2.4	4.3	0.02	7.6	0.83	2.5	44	100	ND
05-May-97	ND	0	19	1.6	2.2	0.02	7.6	0.89	2.9	70	130	ND
06-May-97	ND	0	8	3.0	4.7	0.02	7.9	0.78	2.16	70	140	ND
07-May-97	1	9	7	2.6	3.9	0.02	7.7	0.96	2.36	50	120	ND
09-May-97	ND	23	6	3.0	3.3	0.02	7.9	0.94	2.12	100	180	ND
12-May-97	ND	10	7	3.4	3.6	0.02	7.9	1.27	2.23	80	170	ND
14-May-97	ND	34	8	3.0	3.4	0.03	8.4	0.93	3.17	120	200	ND
16-May-97	ND	0	6	3.4	3.3	0.02	8.7	0.63	1.85	100	180	ND
19-May-97	ND	6	10	3.4	4.0	0.01	8.0	0.89	2.26	100	170	ND
21-May-97	ND	8	9	2.6	3.3	0.01	8.1	0.63	2.48	80	140	ND
23-May-97	ND	84	12	3.5	4.0	0.01	8.2	0.84	3.06	110	170	ND
average	ND	16.1	8.5	2.9	3.7	0.02	8.0	1.10	2.62	81.8	157.7	ND
median	ND	8.0	8.0	3.0	3.9	0.02	7.9	0.89	2.36	80.0	170.0	ND

Table 6

Total Reduction after Snowfluent® Operation

Big Sky, Montana, 1997

	FECAL COLIFORMS	TOTAL SUSPENDED SOLIDS	BOD_5	ORTHOPHOSPHATE AS PHOSPHORUS	TOTAL PHOSPHORUS	NITRATE & NITRITE AS NITROGEN	AMMONIA AS NITROGEN	TOTAL KJELDAHL NITROGEN	ALKALINITY	CONDUCTIVITY	SULFATE
Wastewater											
	col/100ml	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*umhos/cm*	*mg/l*
average	7166.7	20.7	31.8	4.3	6.4	0.07	49.0	21.9	248.3	631.7	27.3
median	6900	21.5	32.5	4.4	7.1	0.00	56.0	20.0	265.0	680.0	26.5
Meltwater											
	col/100ml	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*umhos/cm*	*mg/l*
average	0	16.1	8.5	2.9	3.7	0.00	1.1	2.6	81.8	157.7	0.0
median	0	8.0	8.0	3.0	3.9	0.00	0.9	2.4	80.0	170.0	0.0
Reduction											
	%	%	%	%	%	%	%	%	%	%	%
average	100.0	22.2	73.3	32.6	42.2	100.00	97.8	88.1	67.1	75.0	100.0
median	100.0	62.8	75.4	31.8	45.1		98.4	88.0	69.8	75.0	100.0

Maine, USA, comparing spray irrigation to Snowfluent® in side by side simultaneous operations have shown 40 to 50 mg/l of SO_4 from spray irrigation compared to 1-2 mg/l in the ground water adjacent to the Snowfluent® meltwater application area.

8.1 Discussion of the Results from Westport - Ontario and Carrabassett Valley - Maine

The concentration of nitrate nitrogen in groundwater is the major concern of the general public and therefore is the main topic of the groundwater monitoring program for the Westport and Carrabassett Valley Snowfluent® plants.

In 1994, Delta Engineering began research on "The Biochemical Evaluation of the Groundwater at Snowfluent® Deposit Areas". This was a follow-up to previous studies that were performed. Series of analyses compared groundwater data from a field spray irrigation.

The main sources of nitrogen leaching to the groundwater were systematically investigated. It was concluded that removal of forest growth in the snow deposit areas can result in nitrate leaching to the groundwater. This phenomenon was explained by the fact that following disturbances of the forest ecosystem, decomposition, nutrient mineralization and its deposition were much higher than nutrient uptake from plant growth.

Some fluctuations in specific conductance were also noted. This nitrate release phenomenon only lasts for a short period of time.

Based on the above facts, along with environmental concerns, Delta Engineering continues to monitor and analyze groundwater from all snow deposit sites. Systematic investigations take place at the Snowfluent® plants in Westport, Ontario and in Carrabassett Valley, Maine and in both new installations in Saskatchewan and Maine.

Many factors affect the processes occurring during production, storage, melting of snow and infiltration of meltwater. As well, the modest amount of data available for analysis, made it difficult to completely analyze these results. However, according to the theories and hypotheses about nutrient sources in groundwater and present knowledge about the Snowfluent® process, it was possible to draw the following conclusions:

- Achieved results revealed that all analyzed parameters were at a lower level than the Chemical/Physical Objectives for Drinking Water in USA and Canada.

- The unmanaged, natural forests are nitrogen - conserving. Any manipulations involved in forest ecosystems, which removes the dominant vegetation and thus the ability to take up nutrients, can lead to relatively large nitrogen releases, usually as a nitrate nitrogen to the groundwater.

- Nutrient uptake during the peak of snowpack melting, at the prepared disposal area is limited. Old vegetation is removed and the newly seeded grasses have started to grow at that time. Thus, following removal of the forest, decomposition and mineralization is an additional source for the nitrate leaching effect.

- The civil works on the site, like underground piping system and tower foundations, have changed the local soil characteristics, mainly by increasing its permeability in areas of trenching and excavation. This could significantly increase temporary leaching of nutrients and other elements to the groundwater. It should be noted, that this occurrence after a short period of time would decline rapidly.

Westport, Ontario

The results from the groundwater analyses at Westport Snowfluent® plant for the period 1995-1997 in Appendix C_1 are summarized. Significant parts of this data concern background analyses performed before Snowfluent® operation. The winter of 1996/97 is the first season of Snowfluent® operation.

- There appears to be a small amount of nitrate leaching as shown by increases in nitrate level in well MW#2. The average value of nitrate concentration in well MW#2, before Snowfluent® operation Oct. 95-Nov. 96 was 0.13 mg/l. After operation this value increased to 0.58 mg/l.

- In well MW #4, there was no increase of nitrate leaching into the water table. The average concentration of nitrate in groundwater in well MW #4 before Snowfluent® operation was 0.52 mg/l. After the first year of operation, the nitrate concentration ranged from 0.11 - 0.85 mg/l, with an average of 0.29 mg/l, (in effect, a reduction).

- The Total Phosphorus (TP), as well as Orthophosphate, in the groundwater were typically undetectable or at the threshold of detection.

- Some minor fluctuations of chloride for wells MW#2 and MW#3 were noted.

The monitoring program at the Westport site also includes analyses of surface water around the snow deposit site and the surrounding streams. A comparison of these streams is included in Appendix C_2. The sample point at the NE corner is considered to best represent the quality of the meltwater if we were to be surface discharging. The following observations can be made:

- With a couple of exceptions, the BOD_5 was less than 1 mg/l for most of April and May, when the bulk of the melting occurred. The levels rose at the end of May and the beginning of June, but the background control levels also increased at that time. Therefore there was no detectable change in BOD_5. This surface sample point dried up the second week of June, even though ice crystals melting continued until the beginning of July.

- With a couple of exceptions, the NH_3, NH_4 and TKN were <0.5 mg/l, <0.02 mg/l and <0.5 mg/l respectively, for most of the melting season. The higher levels on March 5th were following heavy rains on the preceding days.

- Nitrate levels were low, with most results < 0.5 mg/l.

- Total Phosphorous levels were very low, with all results <0.1 mg/l.

Carrabassett Valley, Maine

- Results from Carrabassett Valley (Appendix D) showed that the concentrations of impurities in the groundwater from the snow disposal fields were significantly less than the concentration of the same parameters measured in groundwater from the spray irrigation system. Results from testing conducted in 1995 showed that maximum nitrate concentration from the groundwater from the snow deposit areas was 3.75mg/l. During the melting period in May, June and July, it decreased. However, it was higher than the concentration of nitrate nitrogen in a control well situated in the up gradient position. In 1996, the median value of nitrate nitrogen in the groundwater was below 3 mg/l, with a max. of 5 mg/l in one well in October.

- The configuration of the disposal field ground surface in Carrabassett Valley (slope~7°), create favorable conditions for meltwater and the groundwater flow in the direction of the forest. This increase total nitrogen uptake, decreasing the nitrate concentration in the groundwater near well #11 and in smaller percentages near well #9, could be a result of nitrate uptake not only by growing vegetation on the disposal area but also by the snow deposit area's peripheral trees.

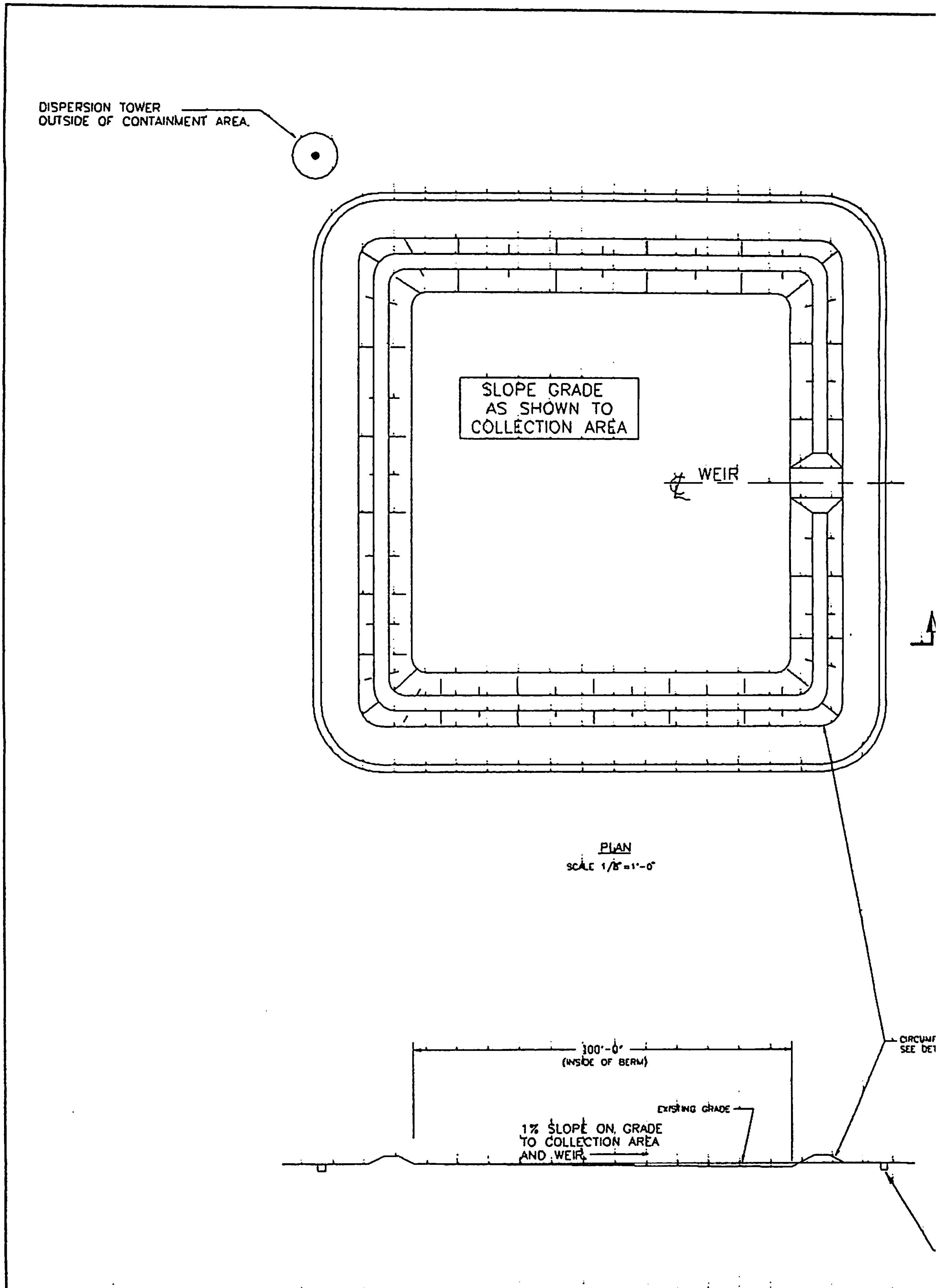
9.0 References

1. Huber, D., Palmateer, G; "Snowfluent", Ontario Ministry of the Environment and Energy Southwest Region report, A Joint Experimental Project Between Southwest Region of the Ministry of the Environment and Group Delta in the Storage and Renovation of Sewage Effluent by Conversion to Snow, (1985).

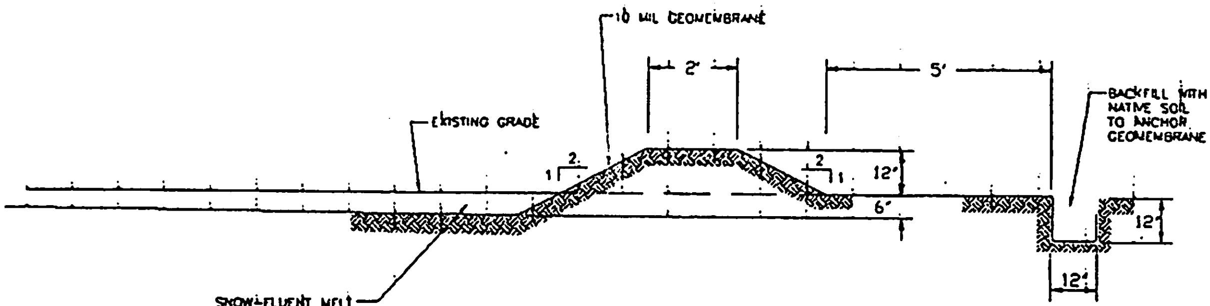
2. United States Environmental Protection Agency; "Land Treatment of Municipal Wastewater", EPA Process Design Manual # EPA 625/1-81-013, chapters. 1-4, (1981).

Appendix A

Snowfluent® Melt Containment Area
Layout and Sections


DISPERSION TOWER
OUTSIDE OF CONTAINMENT AREA.
SLOPE GRADE
AS SHOWN TO
COLLECTION AREA
WEIR
PLAN
SCALE 1/8"=1'-0"
100'-0"
(INSIDE OF BERM)
EXISTING GRADE
1% SLOPE ON GRADE
TO COLLECTION AREA
AND WEIR

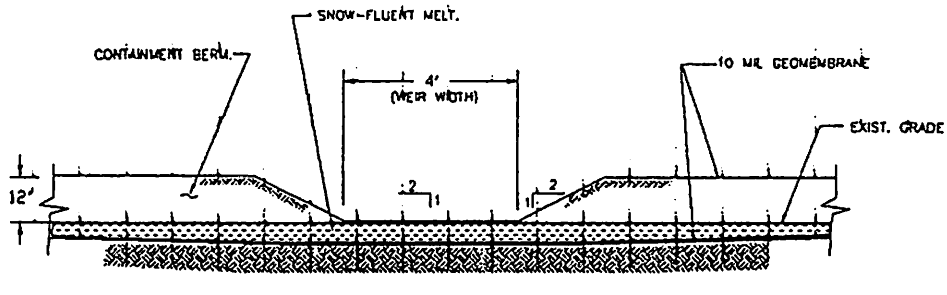
REVISION:



SECTION "A-A"

TYPICAL BERM AND GEOMEMBANE ANCHOR DETAIL

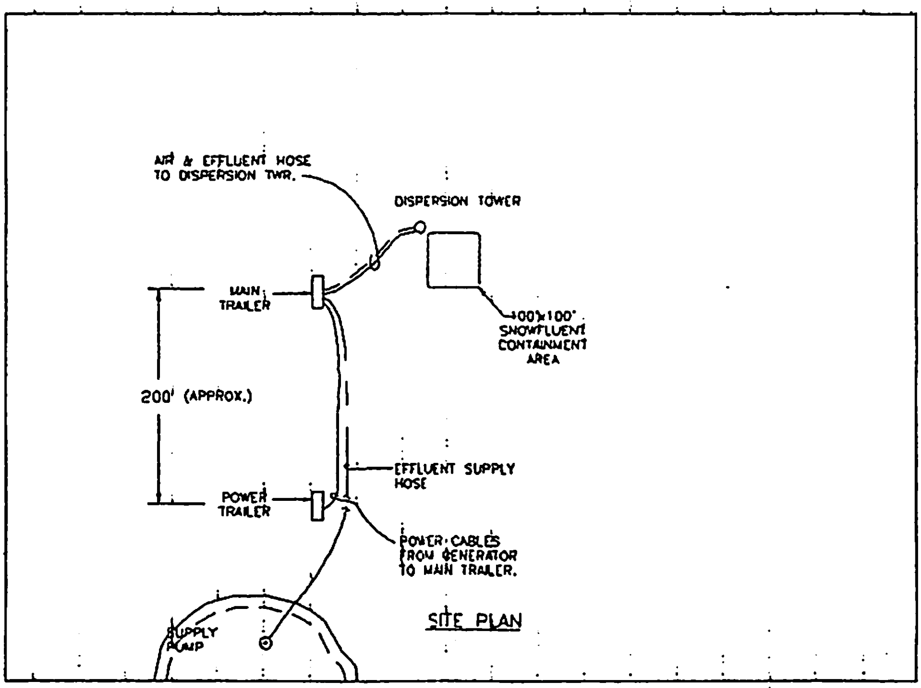
SCALE 1/2"=1'-0"



SECTION "B-B"

SECTIONAL VIEW AT WEIR.

SCALE 1/2"=1'-0"



...ENTIAL BERM
...L @ SECTION "A-A"

GEOMEMBRANE ANCHOR TRENCH SEE DETAIL AT SECTION "A-A".

Rev:	Date:	Description	By:

Drn: M.S.	Des:	Chk:	Sheet:	Job: BIG SKY COUNTY WATER/SEWER DISTRICT #363
Date: 96/10/4	Date:	Date:	Scale: AS SHOWN	Title: SNOWFLUENT MELT CONTAINMENT AREA LAYOUT AND SECTIONS

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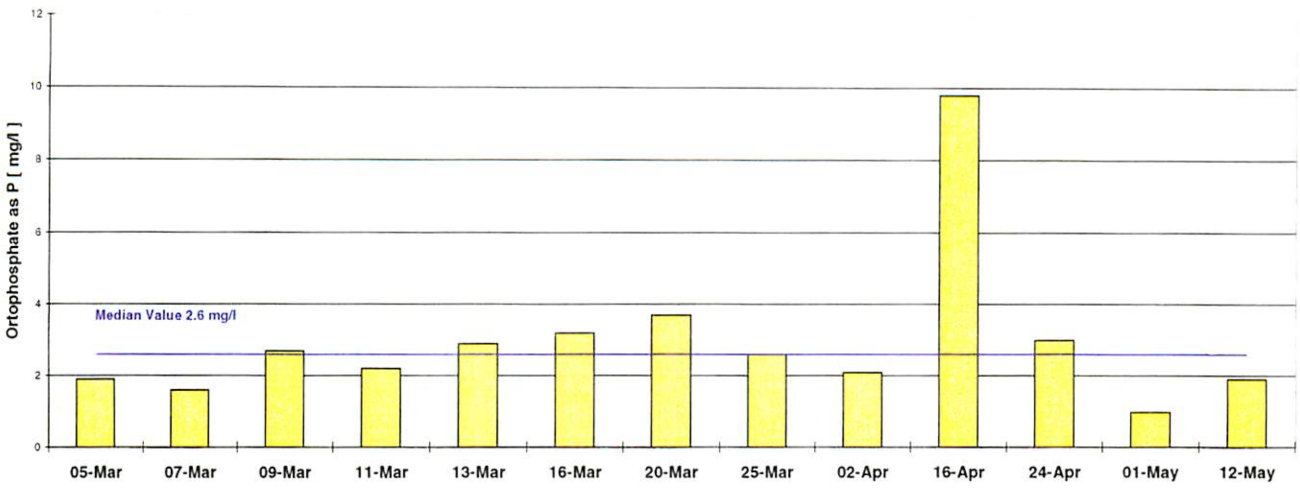
DWG File: P158102 | Dwg.No: P-1561-02 | Rev: P | D

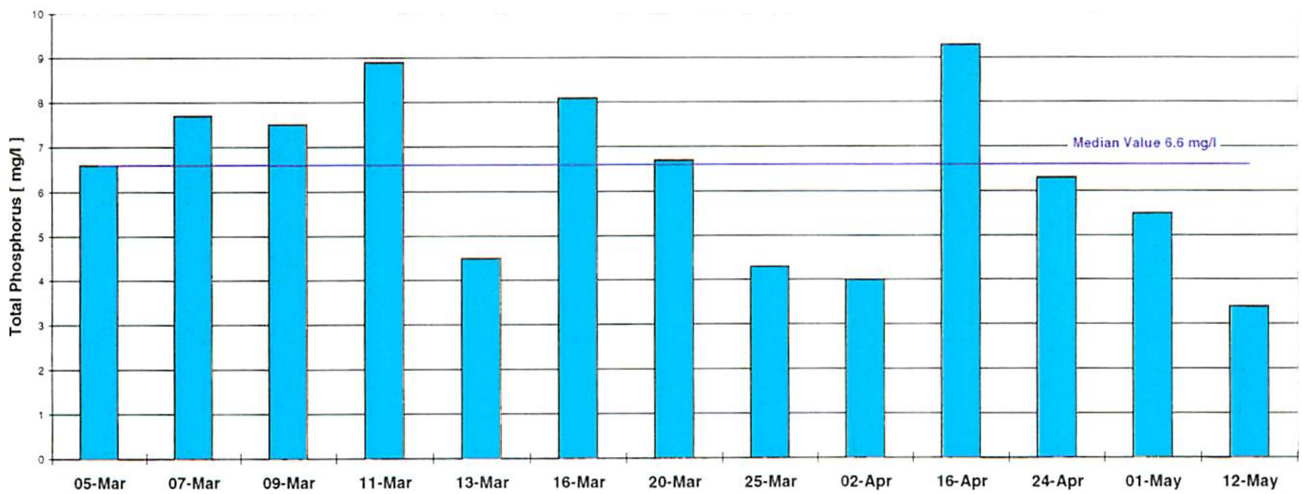
Appendix B1

Results from Analysis of Aged Snowpack
(Big Sky, Montana 1997)

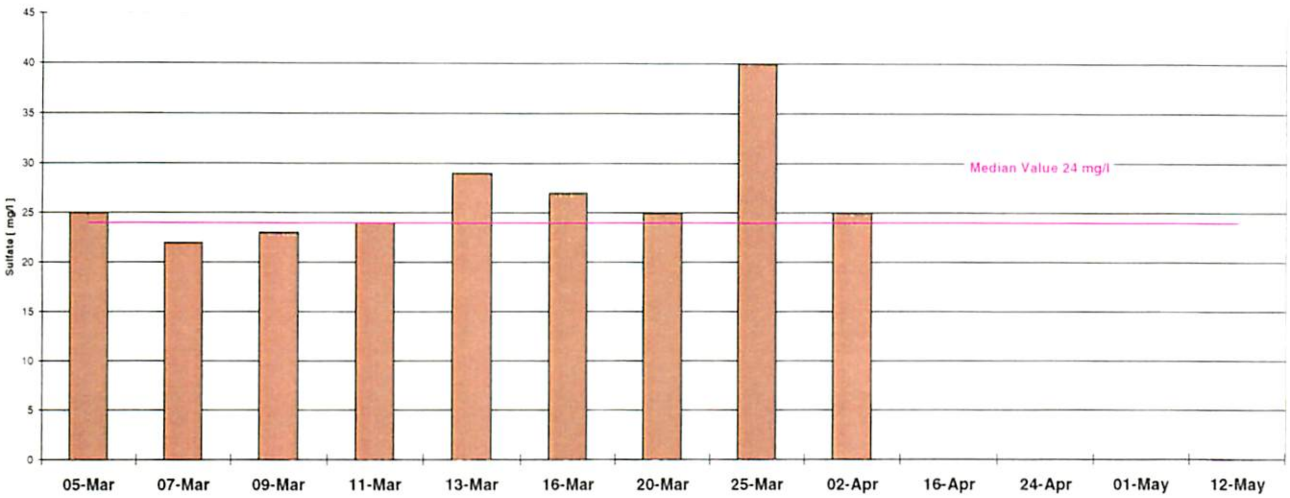
Orthophosphate as Phosphorus in Aged Snowpack, Big Sky - 1997



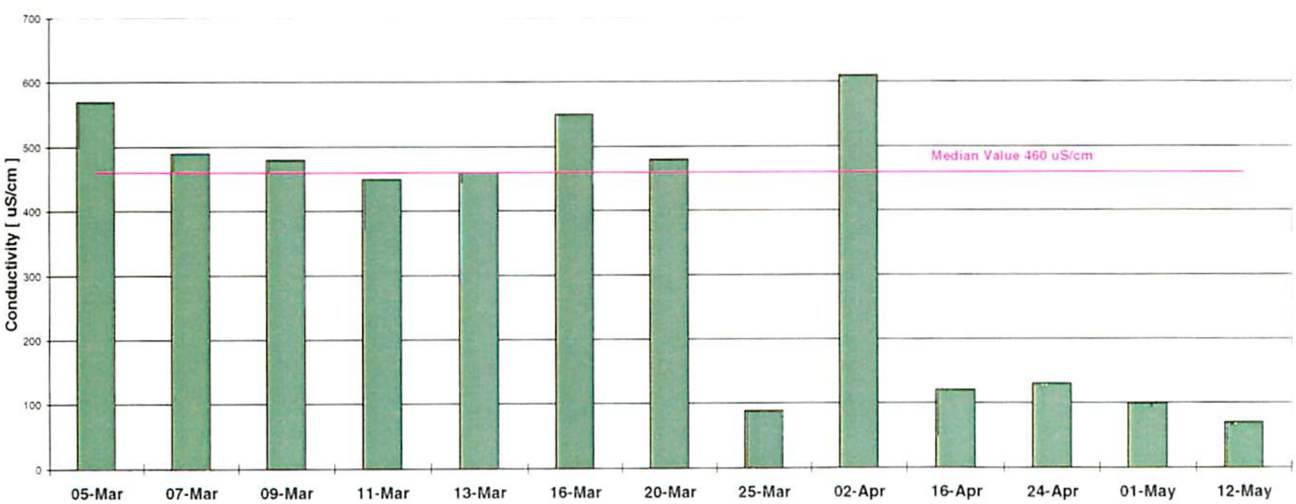
Total Phosphorus in Aged Snowpack, Big Sky - 1997



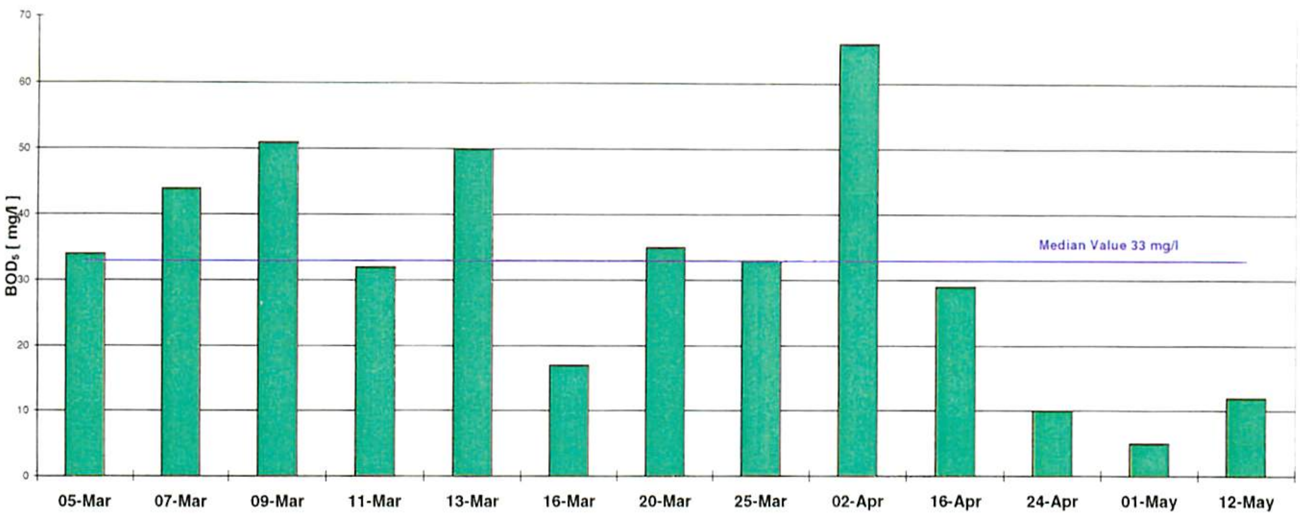
Sulfate in Aged Snowpack, Big Sky 1997



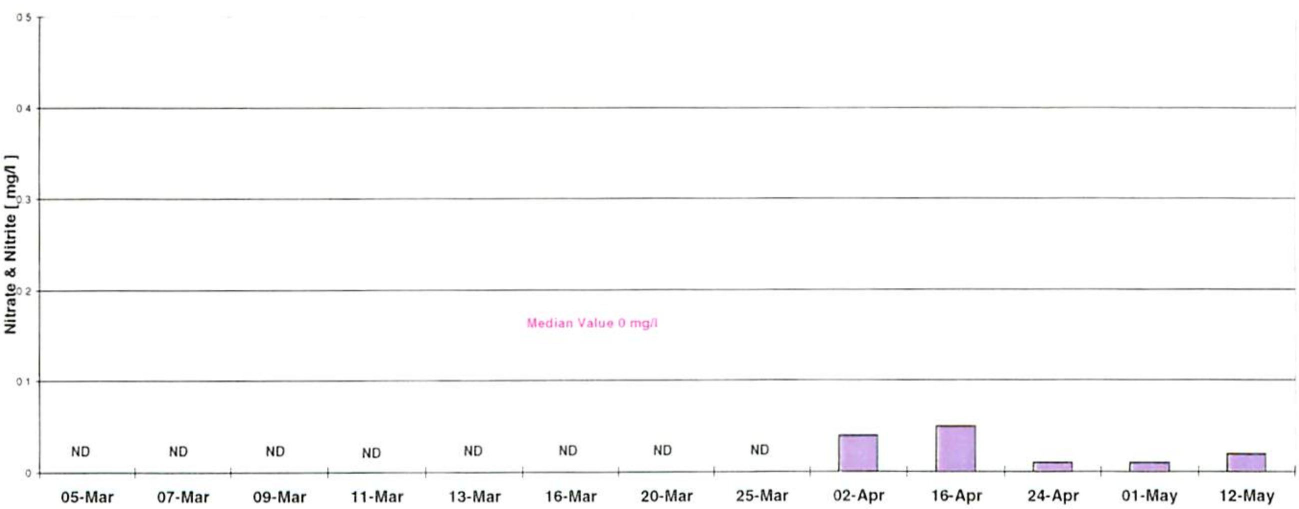
Conductivity of Aged Snowpack, Big Sky - 1997



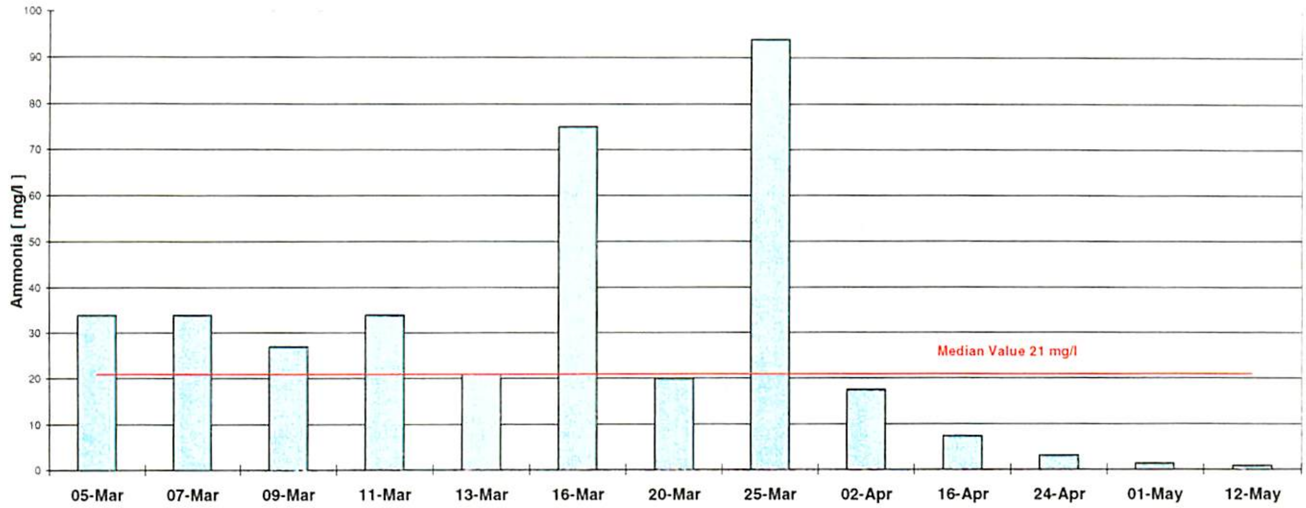
BOD$_5$ of Aged Snowpack, Big Sky - 1997



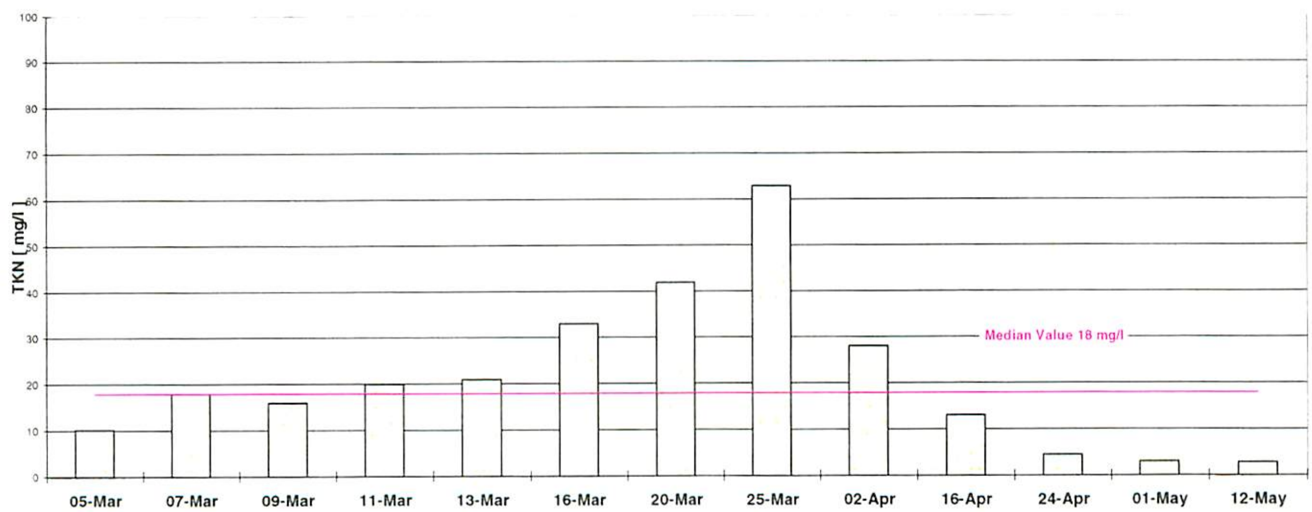
Nitrate and Nitrite in Aged Snowpack, Big Sky - 1997



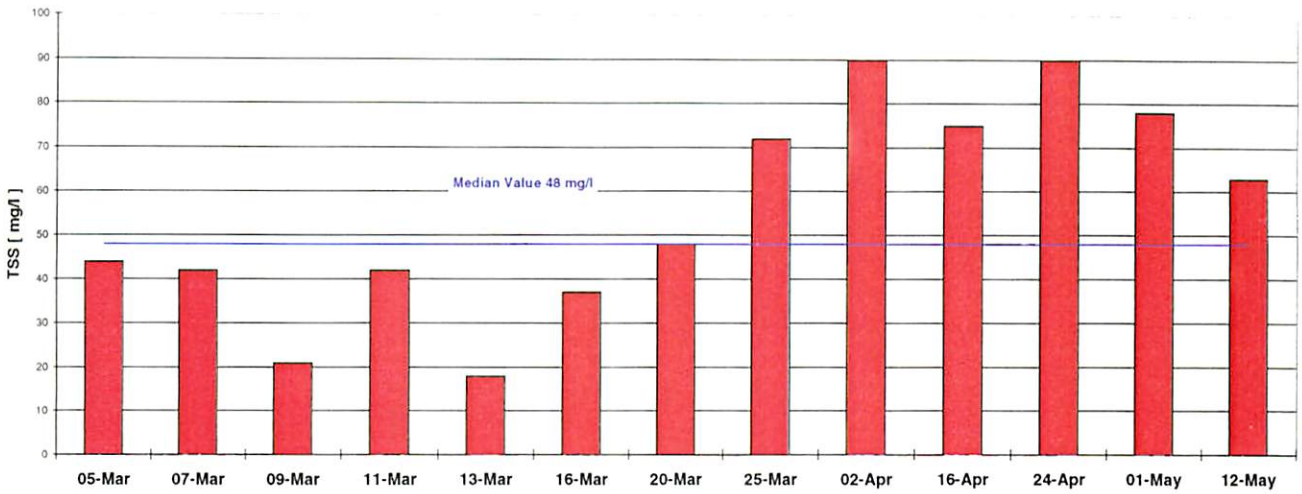
Ammonia in Aged Snowpack, Big Sky - 1997



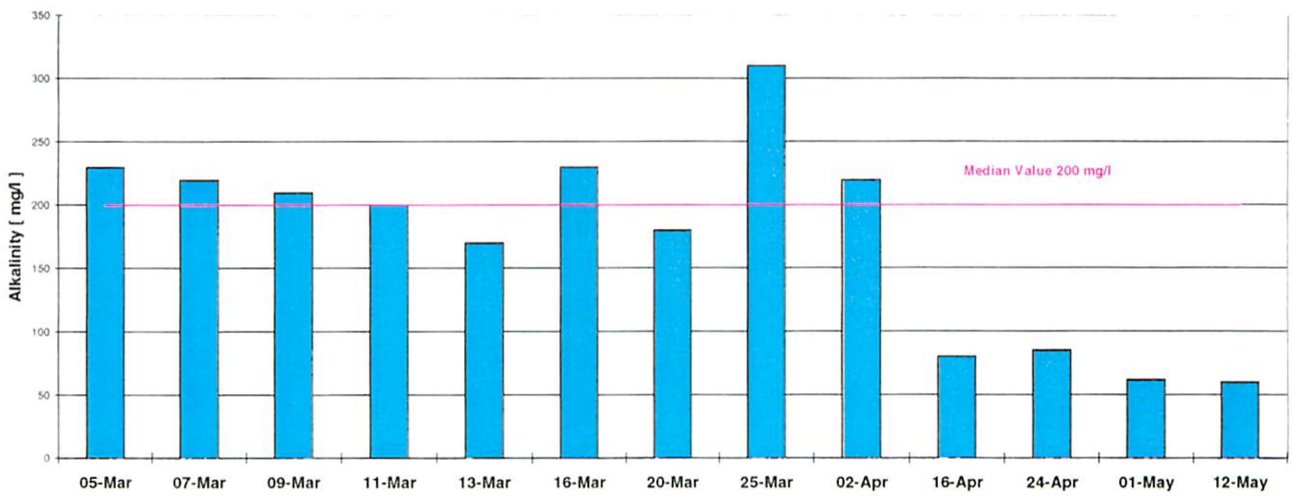
Total Kjeldahl Nitrogen in Aged Snowpack, Big Sky - 1997



Total Suspended Solids in Aged Snowpack, Big Sky - 1997



Alkalinity of Aged Snowpack, Big Sky 1997



Appendix B_2

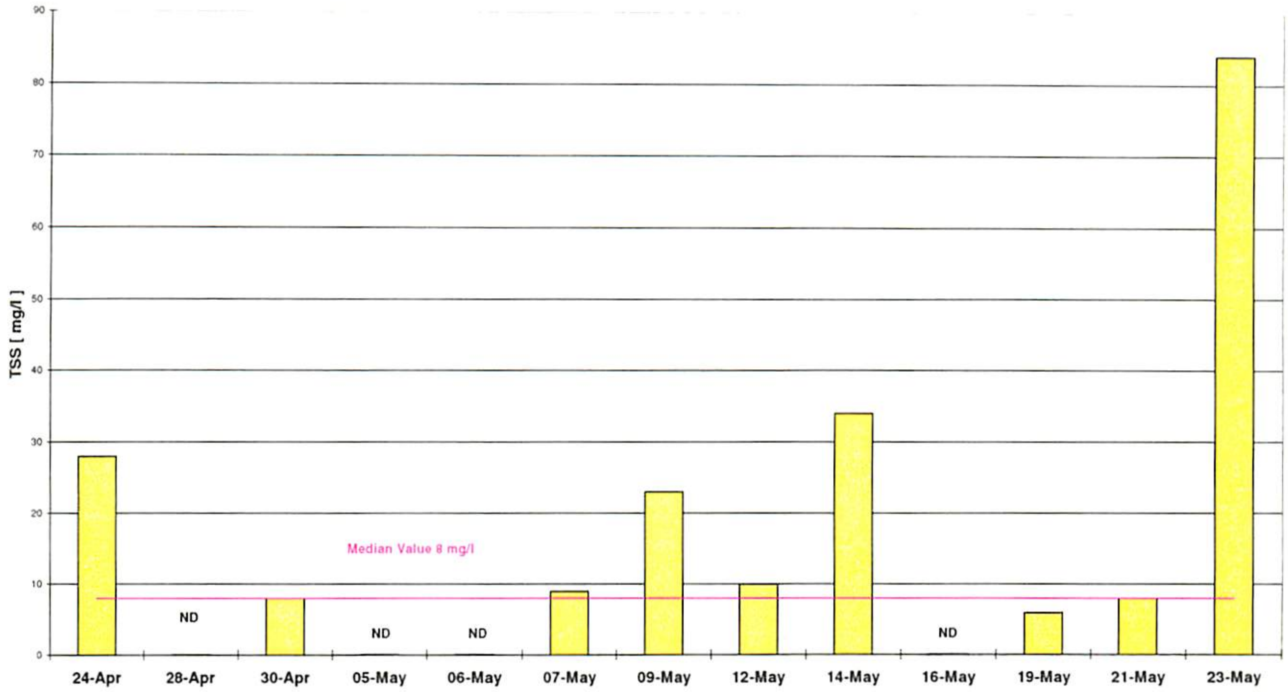
- Results from Analyses of Meltwater

(Big Sky, Montana 1997)

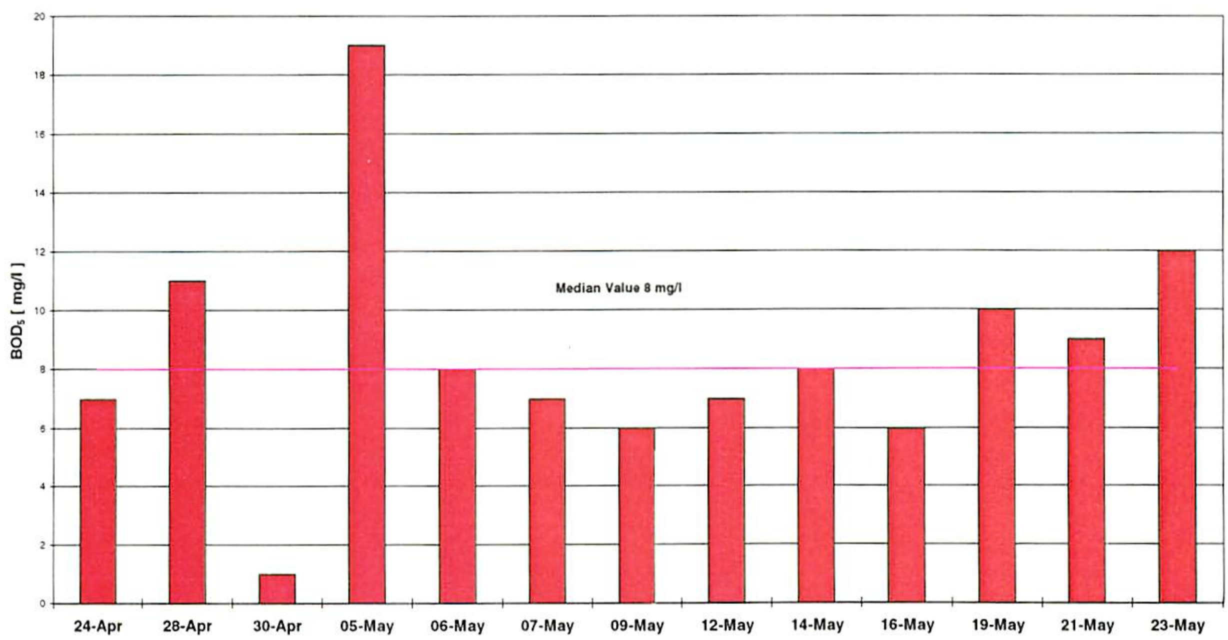
Appendix B2

Results from Analysis of Meltwater
(Big Sky, Montana 1997)

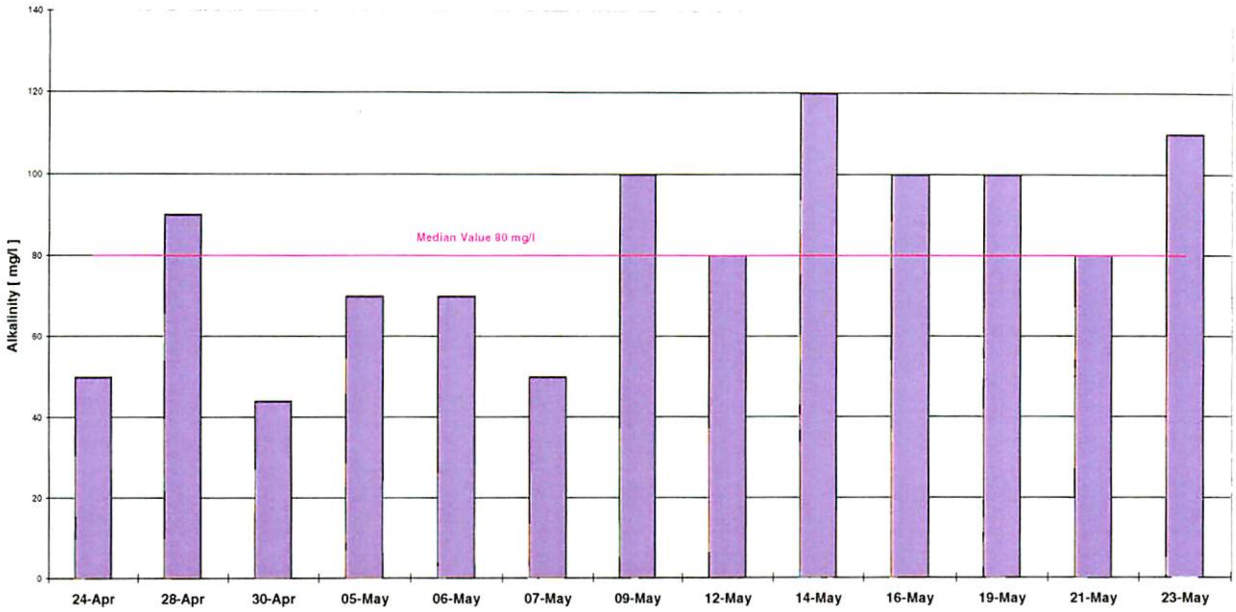
Total Suspended Solids in Meltwater, Big Sky - 1997



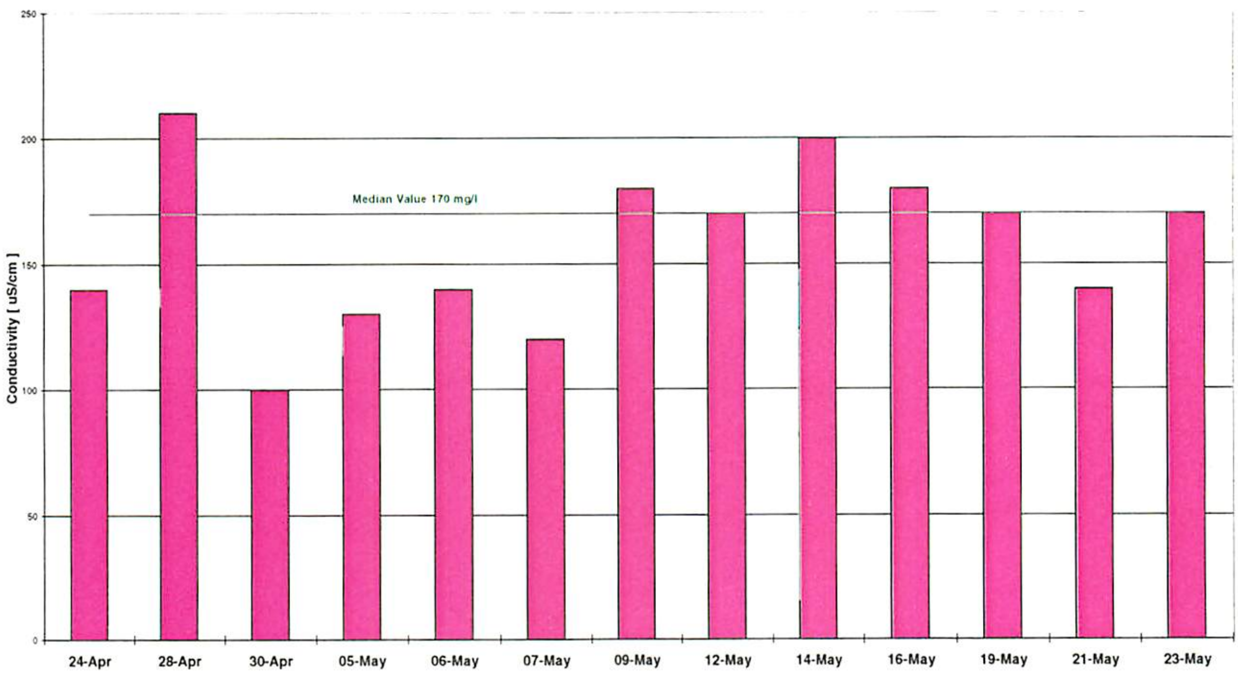
BOD_5 in Meltwater, Big Sky - 1997



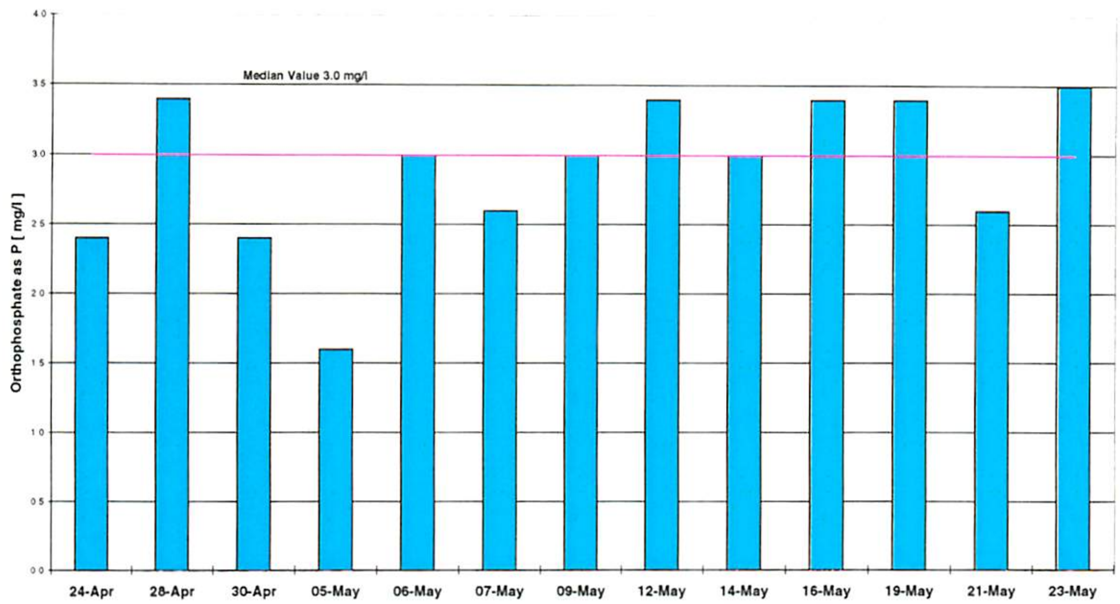
Alkalinity of Meltwater, Big Sky - 1997



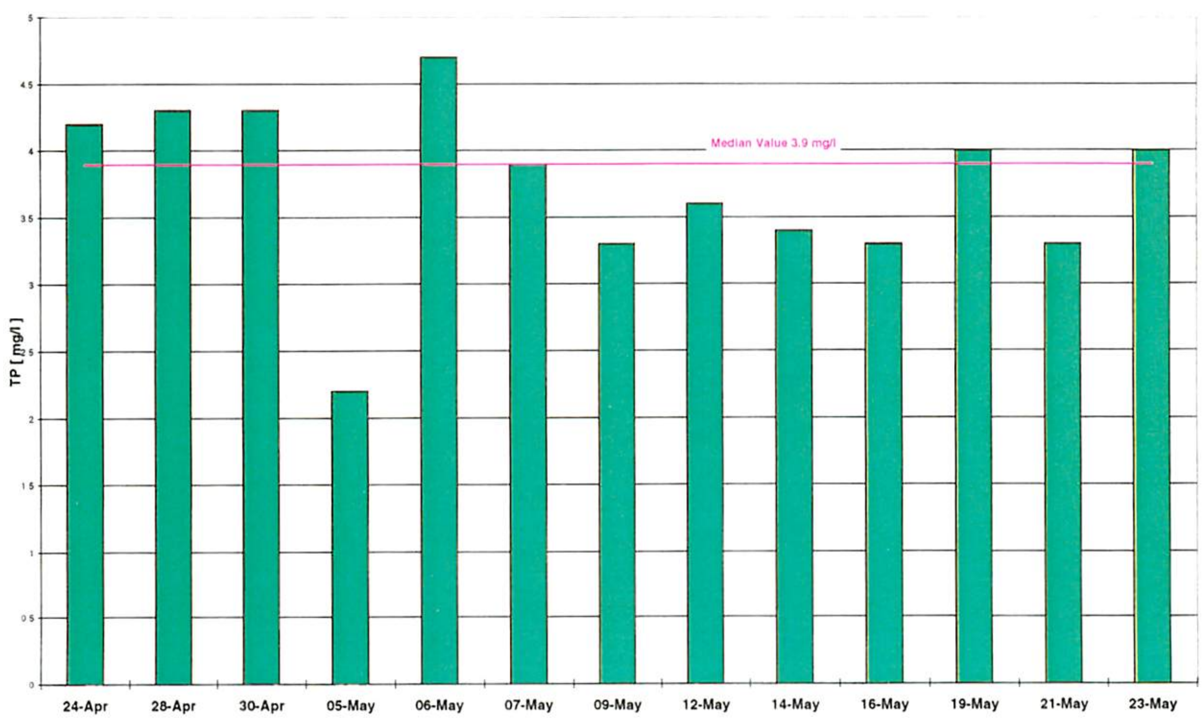
Conductivity of Meltwater, Big Sky - 1997



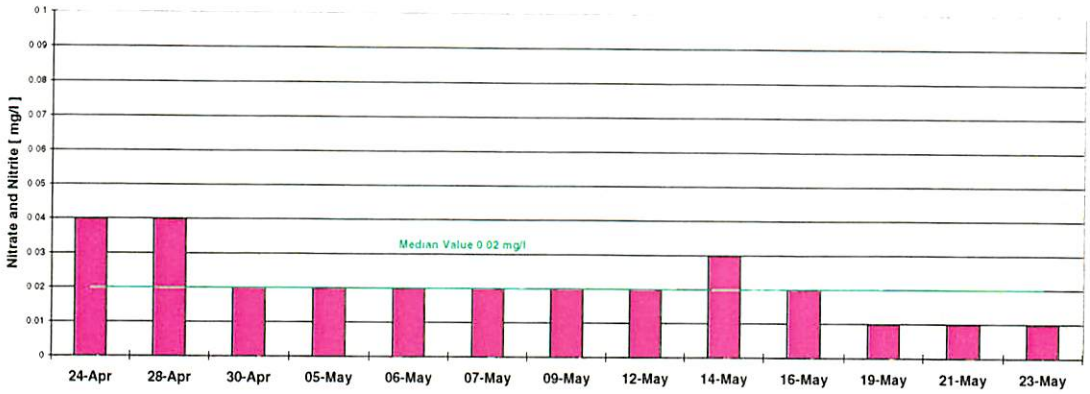
Orthophosphate as Phosphorus in Meltwater, Big Sky, 1997



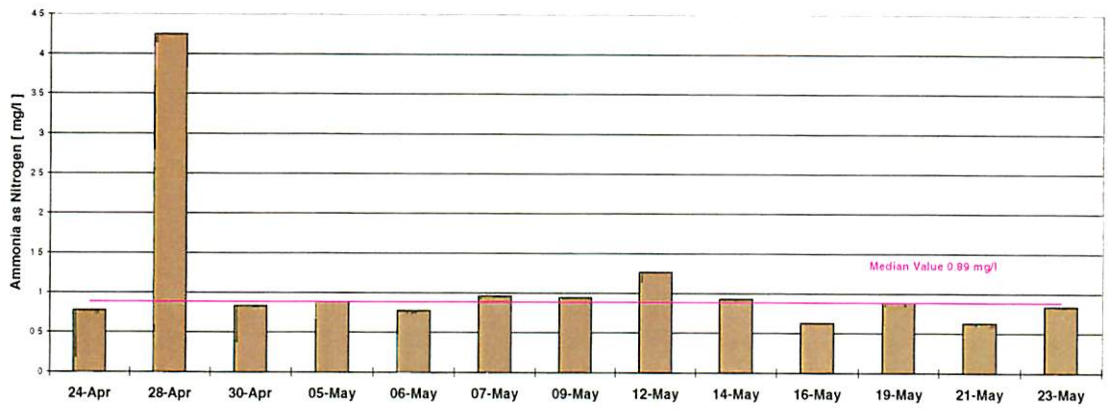
Total Phosphorus in Meltwater, Big Sky - 1997



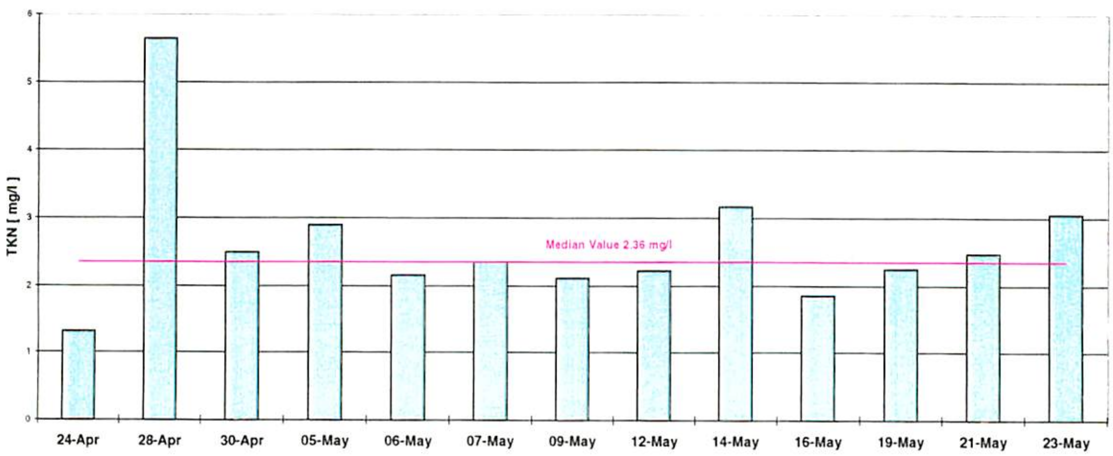
Nitrate and Nitrite as Nitrogen in Meltwater, Big Sky - 1997



Ammonia as Nitrogen in Meltwater, Big Sky - 1997



Total Kjeldahl Nitrogen in Meltwater, Big Sky - 1997



Appendix C1

Groundwater Results
(Westport, Ontario 1977)

Westport Groundwater Sampling Locations 1997

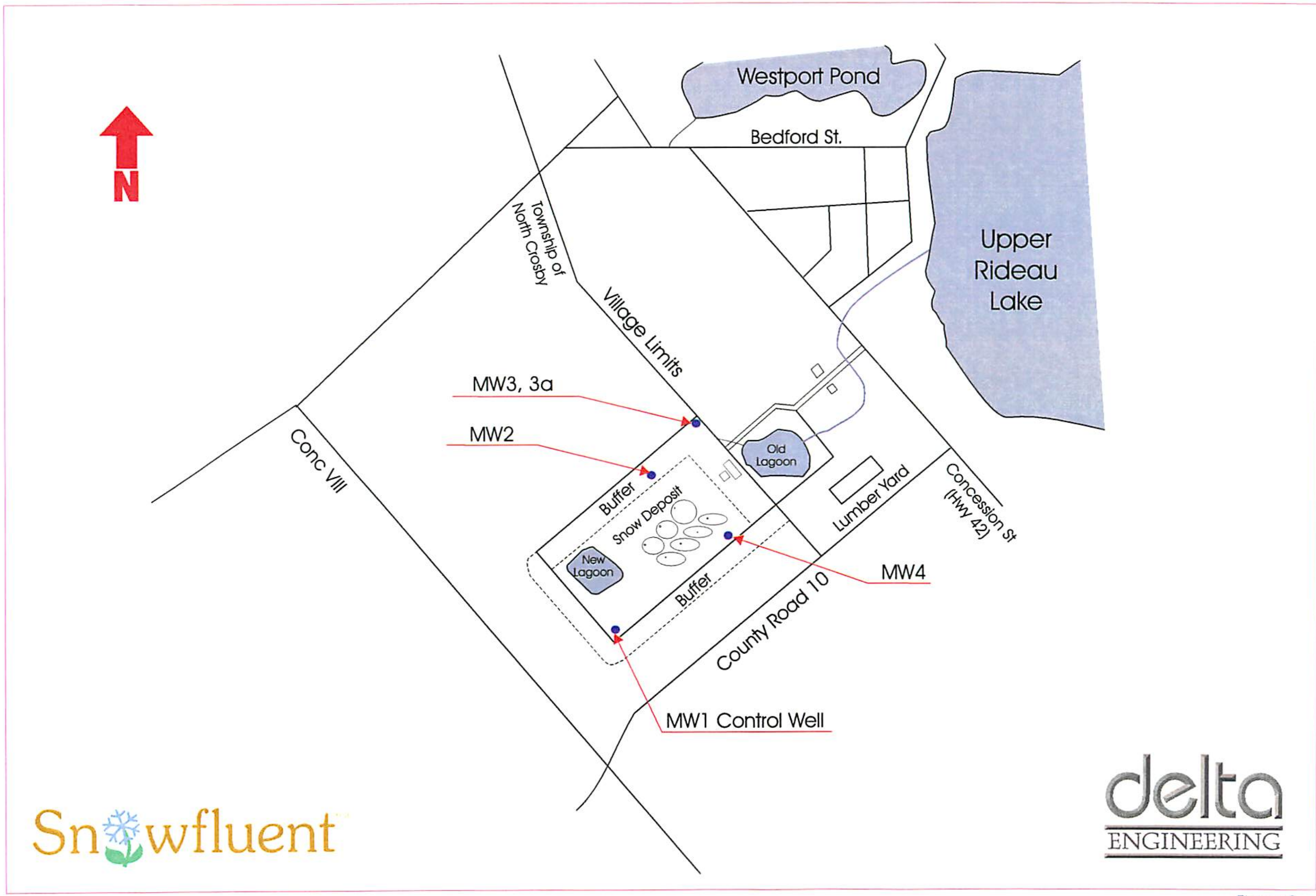


Figure 2

Groundwater Results									
Monitoring Well MW-1									
Date	Total P	$P0_4$	NH_3	NH_4	Conductivity	Cl	NO_3	NO_2	pH
	mg/L	mg/L	mg/L	mg/L	umhos/cm	mg/L	mg/L	mg/L	
Oct. 30/95	-	-	-	-	790	66	1.1	N/D	8
Apr. 3/96	-	-	-	-	-	-	-	-	-
Nov. 1/96	N/D	-	0.07	N/D	435	1	N/D	N/D	8.55
Dec. 18/96	N/D	N/D	0.04	N/D	410	N/D	N/D	N/D	8
Jan. 30/97	N/D	-	0.06	N/D	464	1	N/D	N/D	7.92
Mar.5/97	N/D	N/D	N/D	N/D	462	2	N/D	N/D	7.99
Apr. 3/97	-	-	-	-	-	-	-	-	-
Apr. 29/97	N/D	N/D	0.03	N/D	471	1	N/D	N/D	-
May 27-28/97	N/D	N/D	0.11	N/D	486	1	N/D	N/D	7.71
Jun 18/97	N/D	N/D	N/D	N/D	449	N/D	N/D	N/D	7.99
Jul 16/97	N/D	N/D	0.03	N/D	461	1	N/D	N/D	8.02
Aug 19/97	0.01	N/D	N/D	N/D	498	N/D	N/D	N/D	7.75

Note: N/D indicates levels below method detection limits
The first Snowfluent® operation in this area began in Dec. 1997

Groundwater Results

Monitoring Well MW-2

Date	Total P	PO_4	NH_3	NH_4	Conductivity	Cl	NO_3	NO_2	pH
	mg/L	mg/L	mg/L	mg/L	umhos/cm	mg/L	mg/L	mg/L	
Oct. 30/95	-	-	-	-	510	5.5	0.16	N/D	7.9
Apr. 3/96	0.075	-	N/D	-	480	9.9	0.12	N/D	7.4
Nov. 1/96	0.01	-	0.04	N/D	578	1	0.11	N/D	8.01
Dec. 18/96	0.01	N/D	0.08	N/D	540	9	0.32	N/D	7.79
Jan. 30/97	0.01	-	0.11	N/D	511	12	0.62	N/D	7.45
Mar.5/97	0.07	N/D	0.07	N/D	586	35	0.79	N/D	7.86
Apr. 3/97	-	-	-	-	-	-	-	-	-
Apr. 29/97	N/D	N/D	0.03	N/D	698	67	0.56	N/D	-
May 27-28/97	N/D	N/D	0.24	N/D	604	35	0.27	N/D	7.58
Jun 18/97	N/D	N/D	N/D	N/D	682	41	0.72	N/D	7.89
Jul 16/97	0.01	N/D	N/D	N/D	756	36	0.73	N/D	7.42
Aug 19/97	N/D	N/D	0.02	N/D	811	42	0.67	N/D	7.5

Note: N/D indicates levels below method detection limits
The first Snowfluent® operation in this area began in Dec. 1997

Groundwater Results									
Monitoring Well MW-3									
Date	Total P	PO_4	NH_3	NH_4	Conductivity	Cl	NO_3	NO_2	pH
	mg/L	*mg/L*	*mg/L*	*mg/L*	*umhos/cm*	*mg/L*	*mg/L*	*mg/L*	
Oct. 30/95	-	-	-	-	800	58	0.97	N/D	7.9
Apr. 3/96	0.016	-	N/D	-	510	9.1	0.02	0.01	7.2
Nov. 1/96	N/D	-	0.05	N/D	547	9	N/D	N/D	8.05
Dec. 18/96	N/D	N/D	0.02	N/D	547	9	N/D	N/D	7.86
Jan. 30/97	-	-	-	-	-	-	-	-	-
Mar.5/97	-	-	-	-	-	-	-	N/D	-
Apr. 3/97	-	-	-	-	-	-	-	-	-
Apr. 29/97	N/D	N/D	0.02	N/D	577	23	N/D	N/D	-
May 27-28/97	N/D	N/D	0.05	N/D	580	24	N/D	N/D	7.36
Jun 18/97	0.02	N/D	N/D	N/D	571	21	N/D	N/D	7.91
Jul 16/97	N/D	N/D	0.04	N/D	569	18	N/D	N/D	7.75
Aug 19/97	0.01	N/D	0.02	N/D	599	21	N/D	N/D	7.64

Note: N/D indicates levels below method detection limits
The first Snowfluent® operation in this area began in Dec. 1997

Groundwater Results

Monitoring Well MW-3A

Date	Total P	PO_4	NH_3	NH_4	Conductivity	Cl	NO_3	NO_2	pH
	mg/L	mg/L	mg/L	mg/L	umhos/cm	mg/L	mg/L	mg/L	
Oct. 30/95	-	-	-	-	-	-	-	-	-
Apr. 3/96	-	-	-	-	-	-	-	-	-
Nov. 1/96	-	-	-	-	-	-	-	-	-
Dec. 18/96	-	-	-	-	-	-	-	-	-
Jan. 30/97	-	-	-	-	-	-	-	-	-
Mar.5/97	-	-	-	-	-	-	-	-	-
Apr. 3/97	-	-	-	-	-	-	-	-	-
Apr. 29/97	-	-	-	-	-	-	-	-	-
May 27-28/97	N/D	N/D	0.05	N/D	570	27	N/D	N/D	7.38
Jun 18/97	0.01	N/D	N/D	N/D	557	24	N/D	N/D	7.89
Jul 16/97	N/D	N/D	0.02	N/D	558	19	N/D	N/D	7.75
Aug 19/97	N/D	N/D	N/D	N/D	579	19	N/D	N/D	7.62

Note: N/D indicates levels below method detection limits
The first Snowfluent® operation in this area began in Dec. 1997

Groundwater Results									
Monitoring Well MW-4									
Date	Total P	PO_4	NH_3	NH_4	Conductivity	Cl	NO_3	NO_2	pH
	mg/L	mg/L	mg/L	mg/L	umhos/cm	mg/L	mg/L	mg/L	
Oct. 30/95	-	-	-	-	500	32	0.44	0.15	8.1
Apr. 3/96	0.016	-	0.4	-	310	3.1	0.27	0.01	7.3
Nov. 1/96	-	-	0.04	N/D	275	3	0.85	N/D	7.36
Dec. 18/96	0.01	N/D	N/D	N/D	517	2	0.56	N/D	7.87
Jan. 30/97	-	-	-	-	-	-	-	-	-
Mar.5/97	0.03	N/D	0.03	N/D	519	3	0.5		7.84
Apr. 3/97									
Apr. 29/97	N/D	N/D	0.02	N/D	542	5	0.45	N/D	-
May 27-28/97	N/D	N/D	0.12	N/D	531	8	N/D	N/D	7.47
Jun 18/97	-	-	-	-	-	-	-	-	
Jul 16/97	0.01	N/D	0.03	N/D	582	3	0.11	N/D	7.83
Aug 19/97	N/D	N/D	N/D	N/D	580	3	0.14	N/D	7.83

Note: N/D indicates levels below method detection limits
The first Snowfluent® operation in this area began in Dec. 1997

Appendix C2

Surface Water Results
(Westport, Ontario 1997)

Westport Surface Sampling Locations 1997

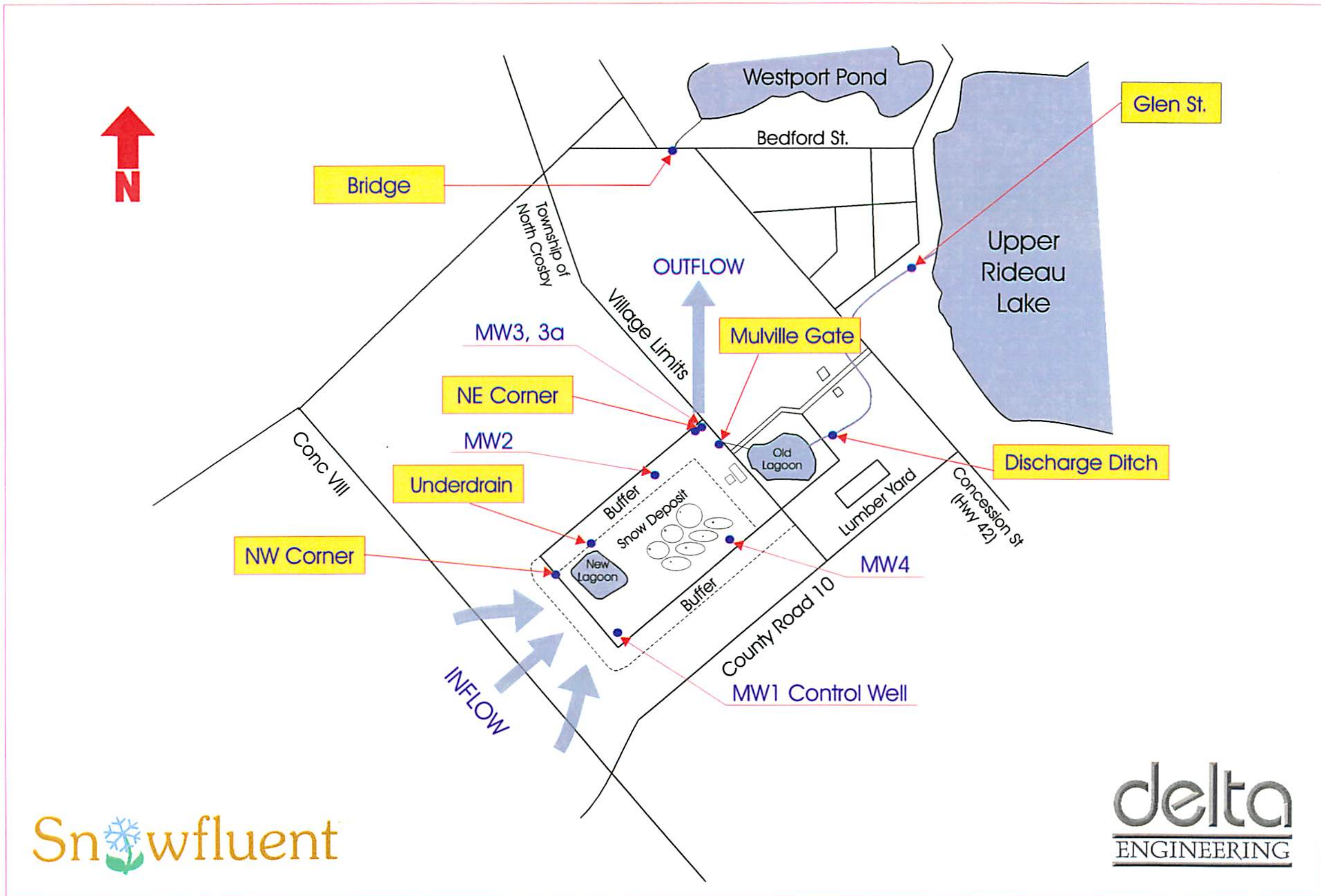
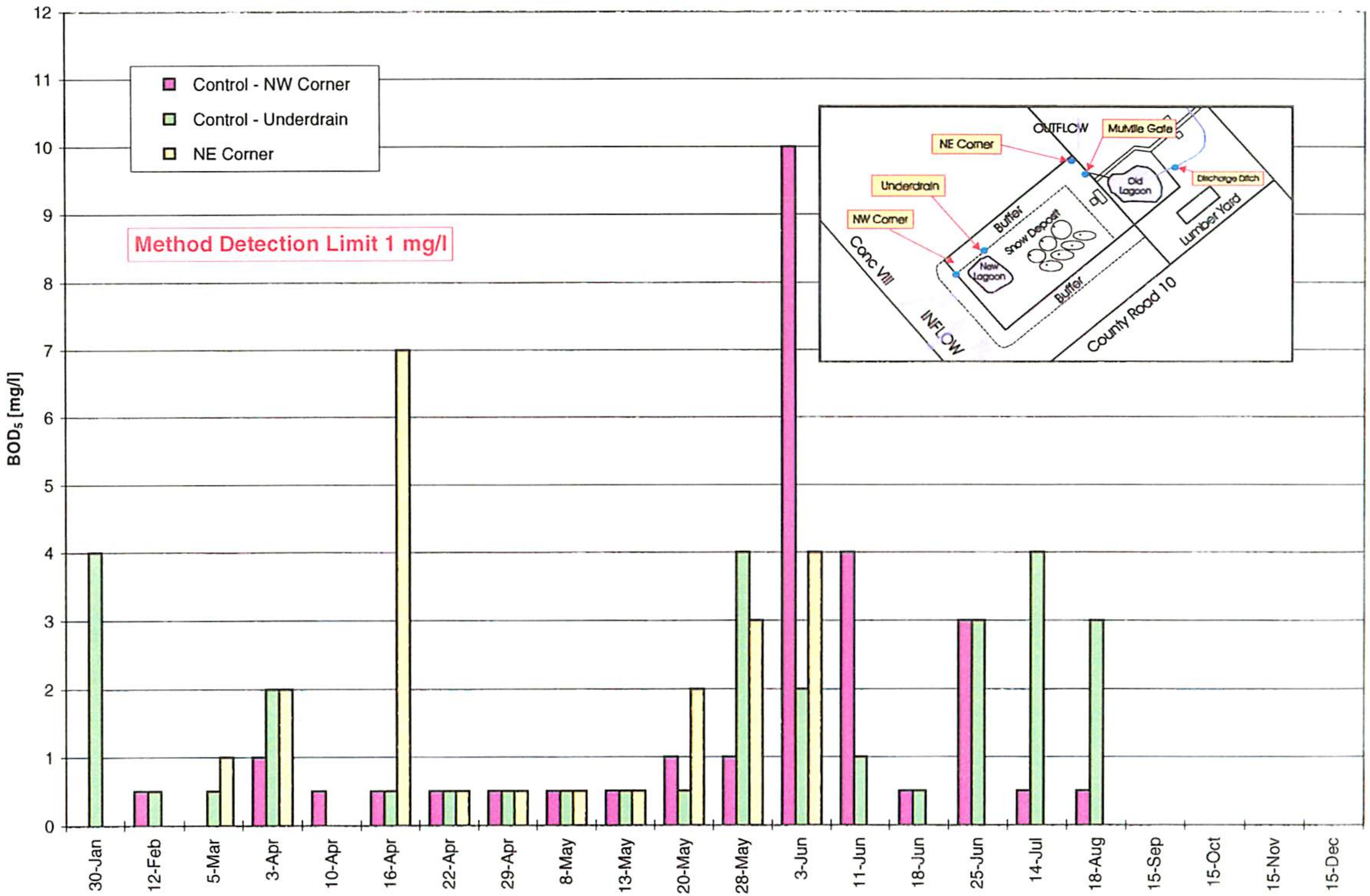


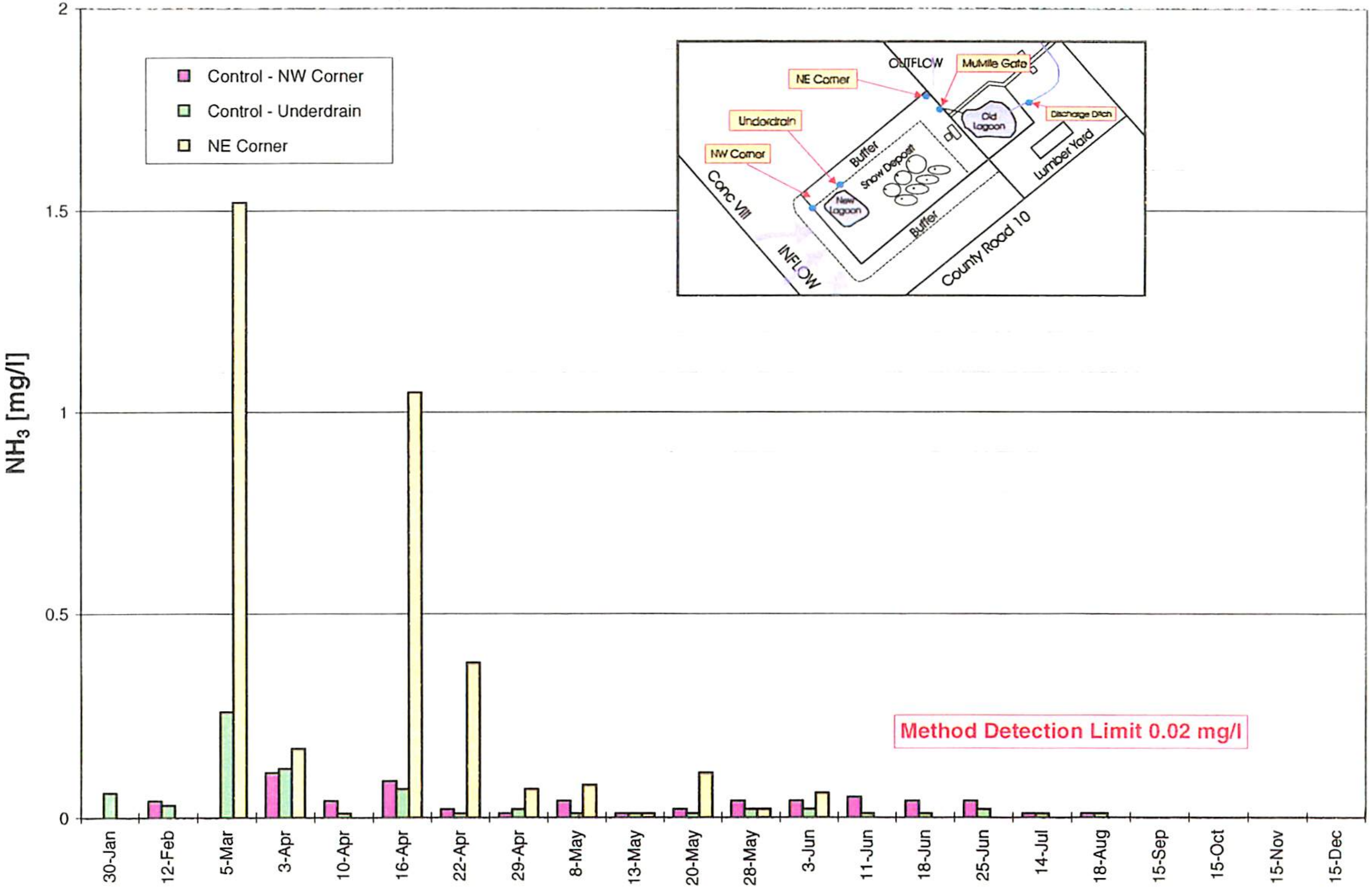
Figure 1

Surface Water Analyses - BOD_5, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



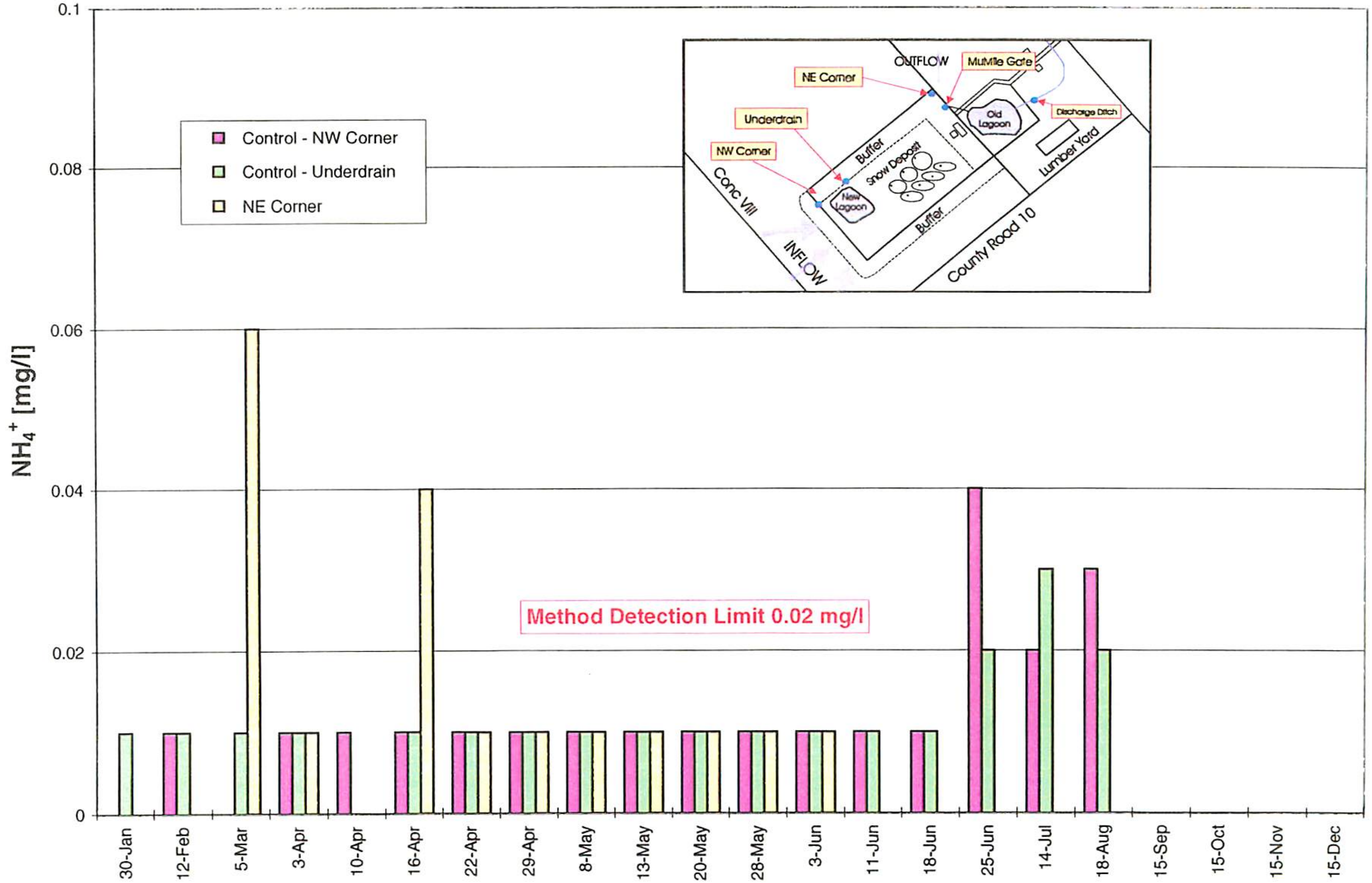
Delta Engineering
Ottawa

Surface Water Analyses - Ammonia NH_3, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



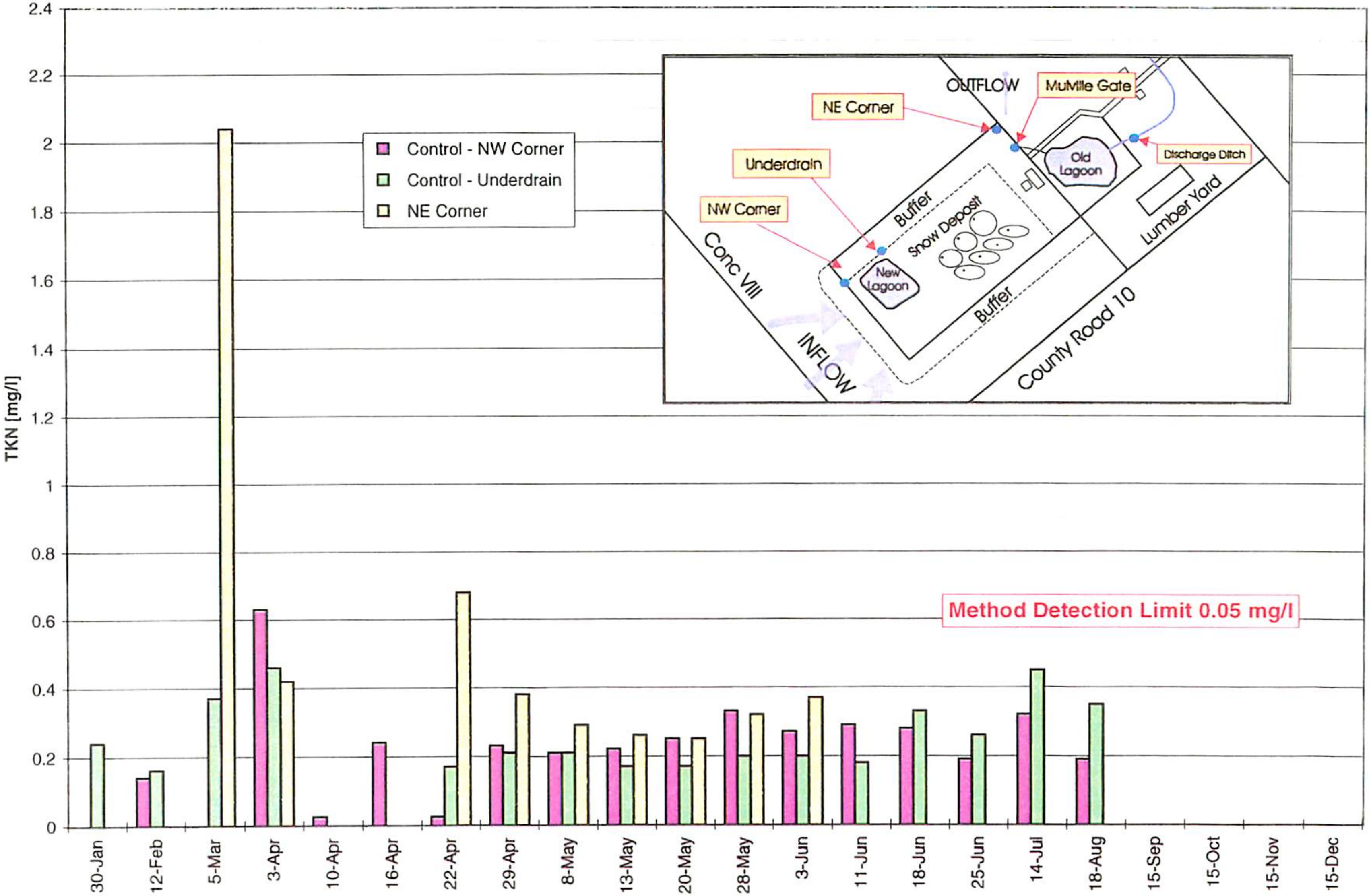
Delta Engineering
Ottawa

Surface Water Analyses - Ammonia NH_4^+, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



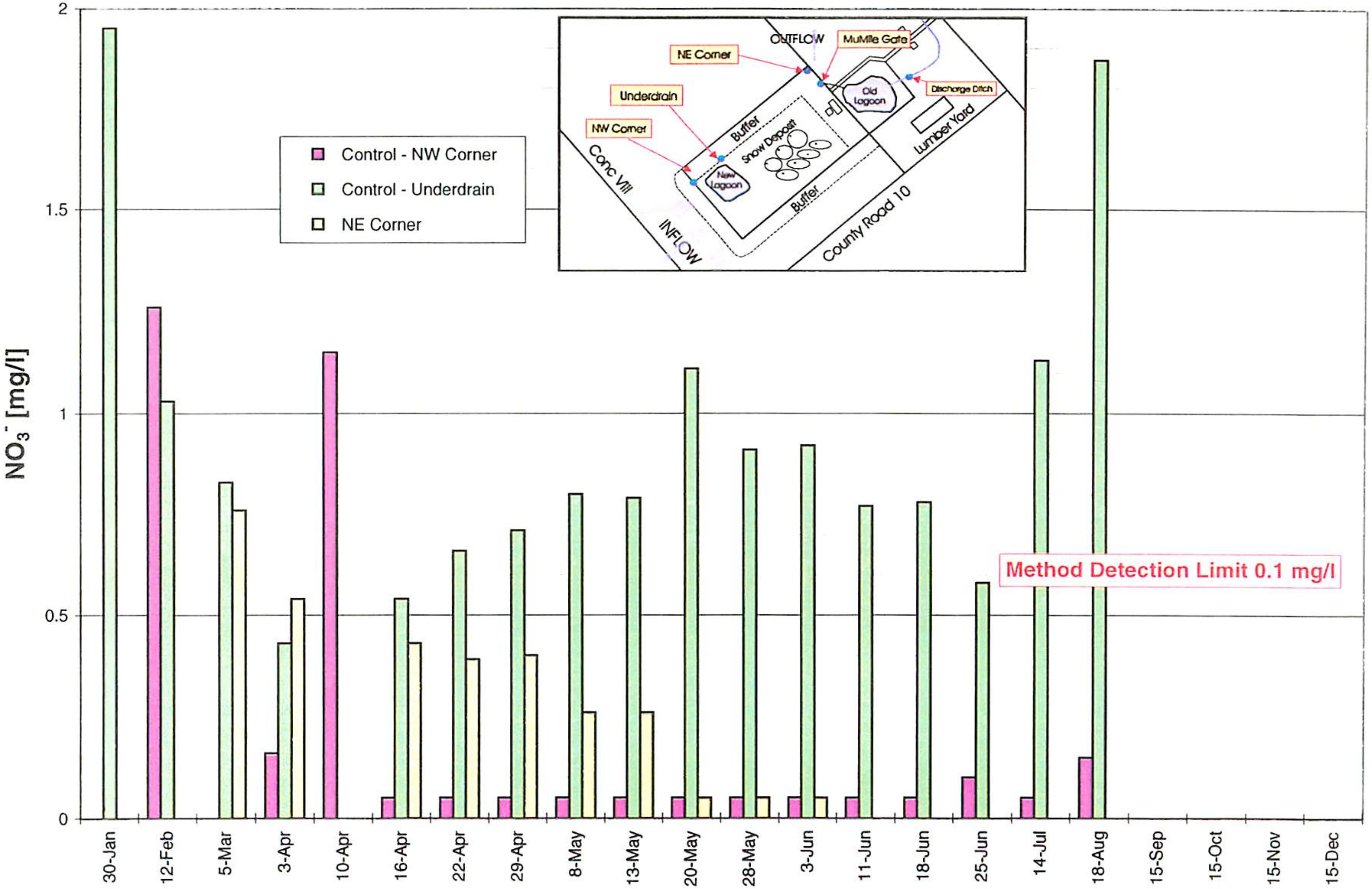
Delta Engineering
Ottawa

Surface Water Analyses - TKN, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



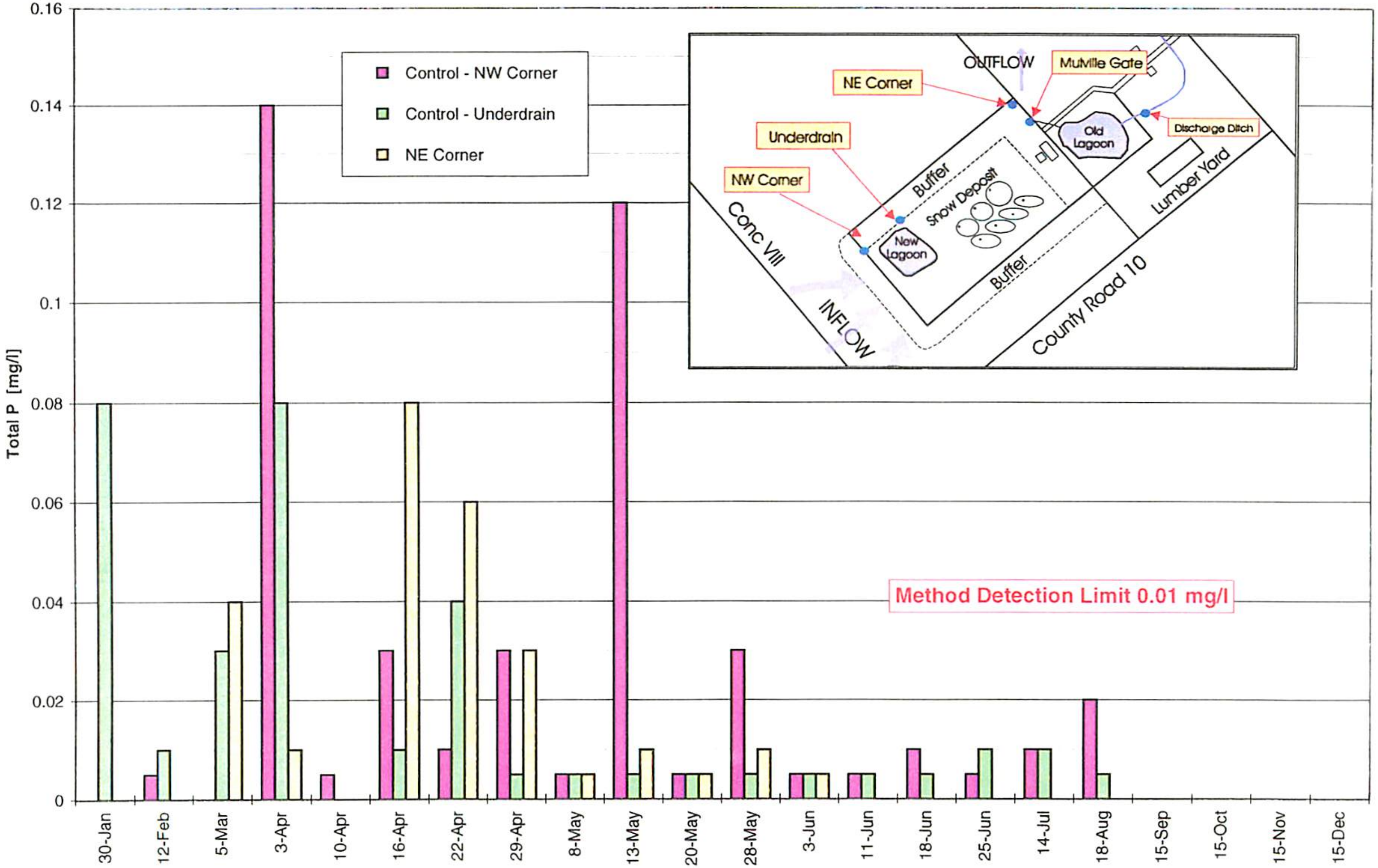
Delta Engineering
Ottawa

Surface Water Analyses - NO_3^-, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



Delta Engineering
Ottawa

Surface Water Analyses - Total P, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



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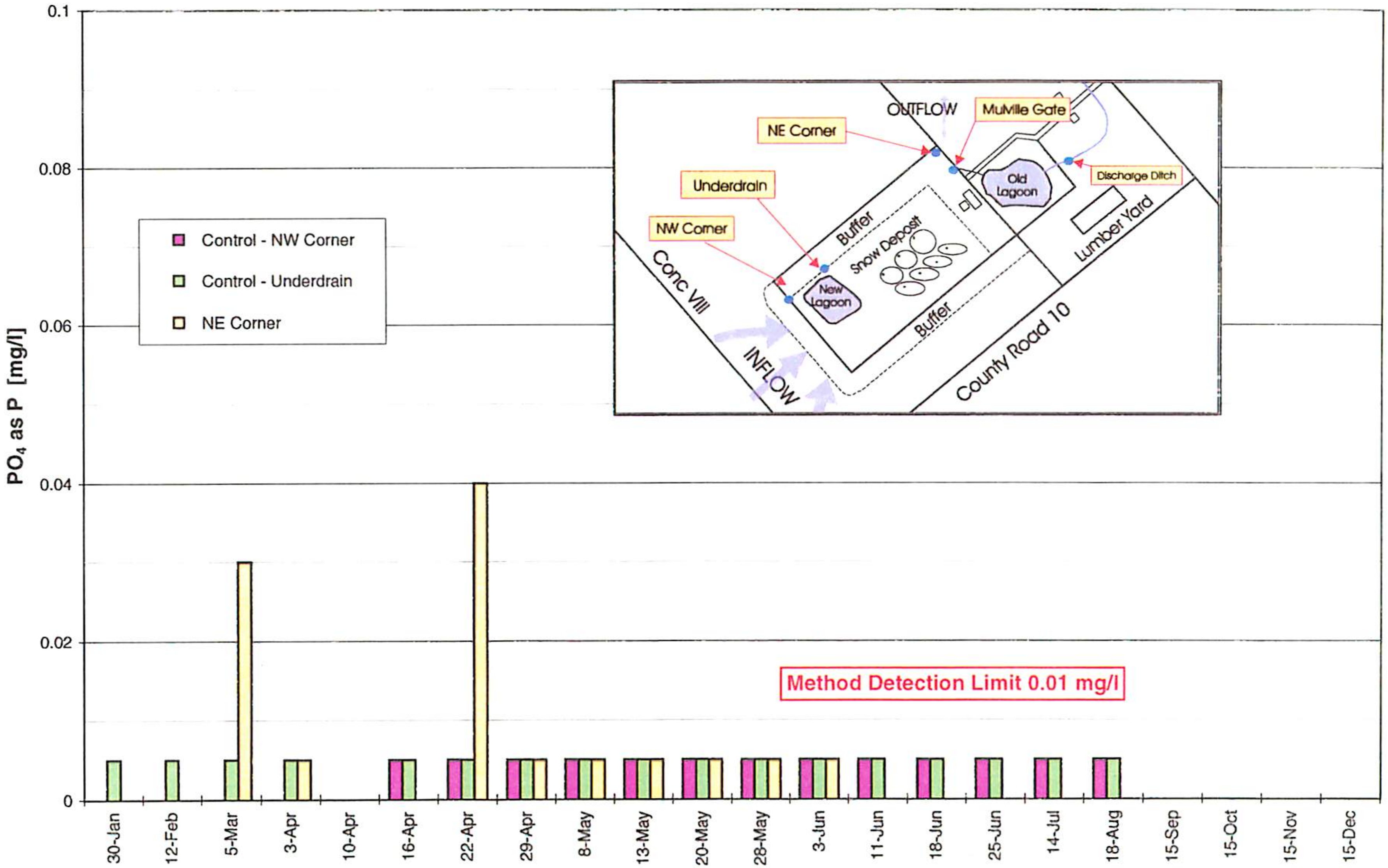
Ottawa

Surface Water Analyses - PO_4 as P, NE Corner
Atomizing Freeze Crystallization - Snowfluent™ Plant. Westport, ON, 1997



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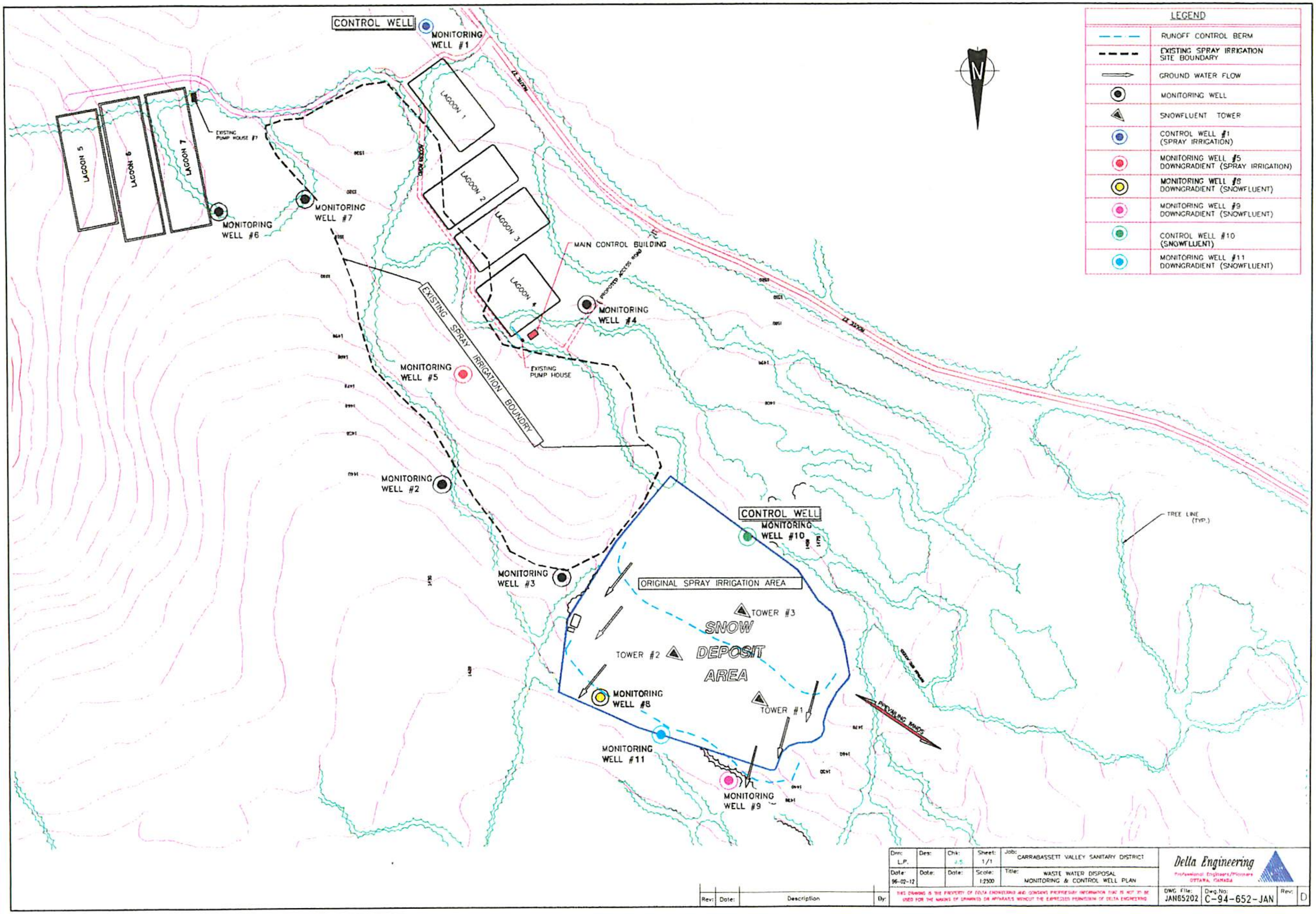
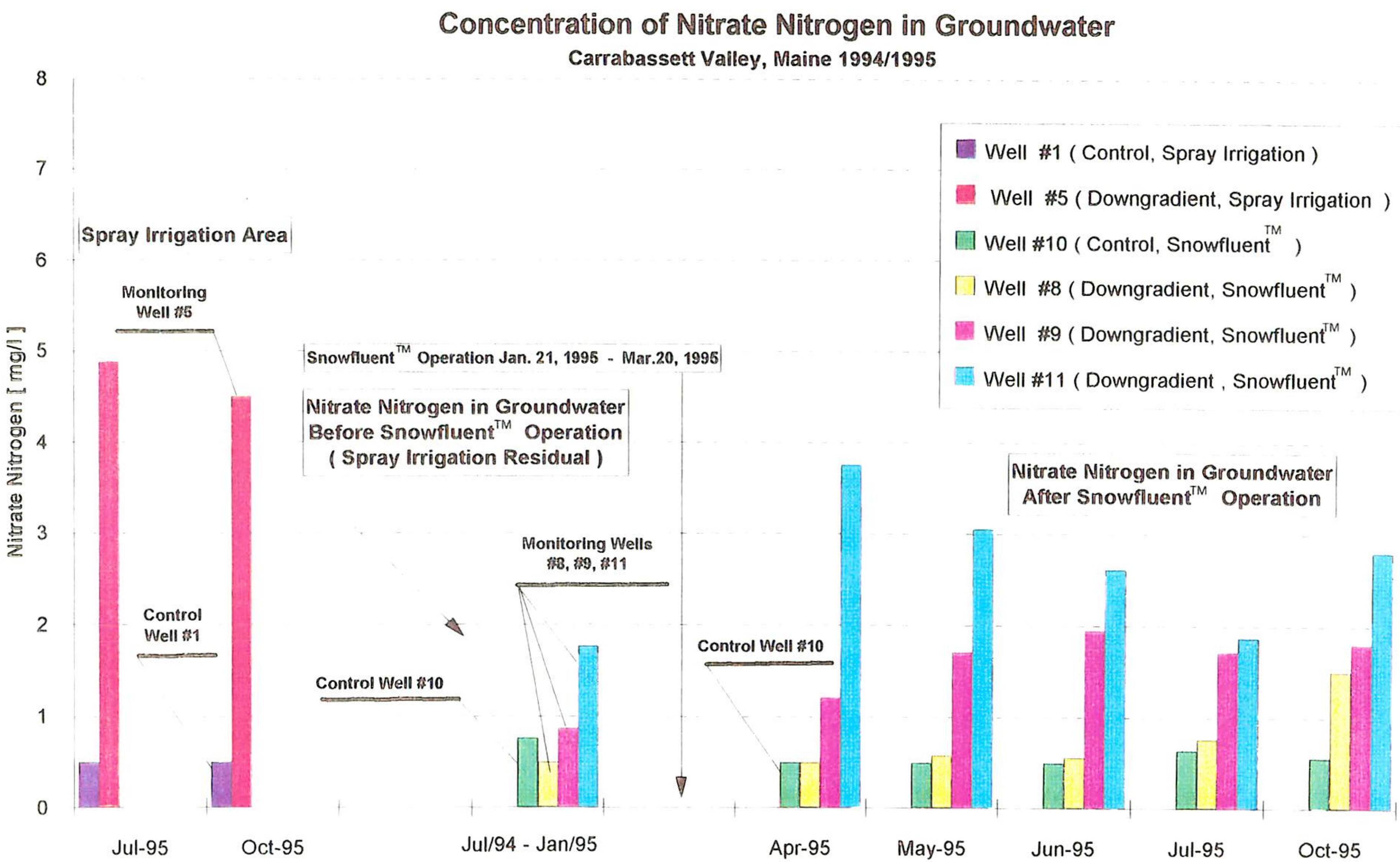
Appendix D

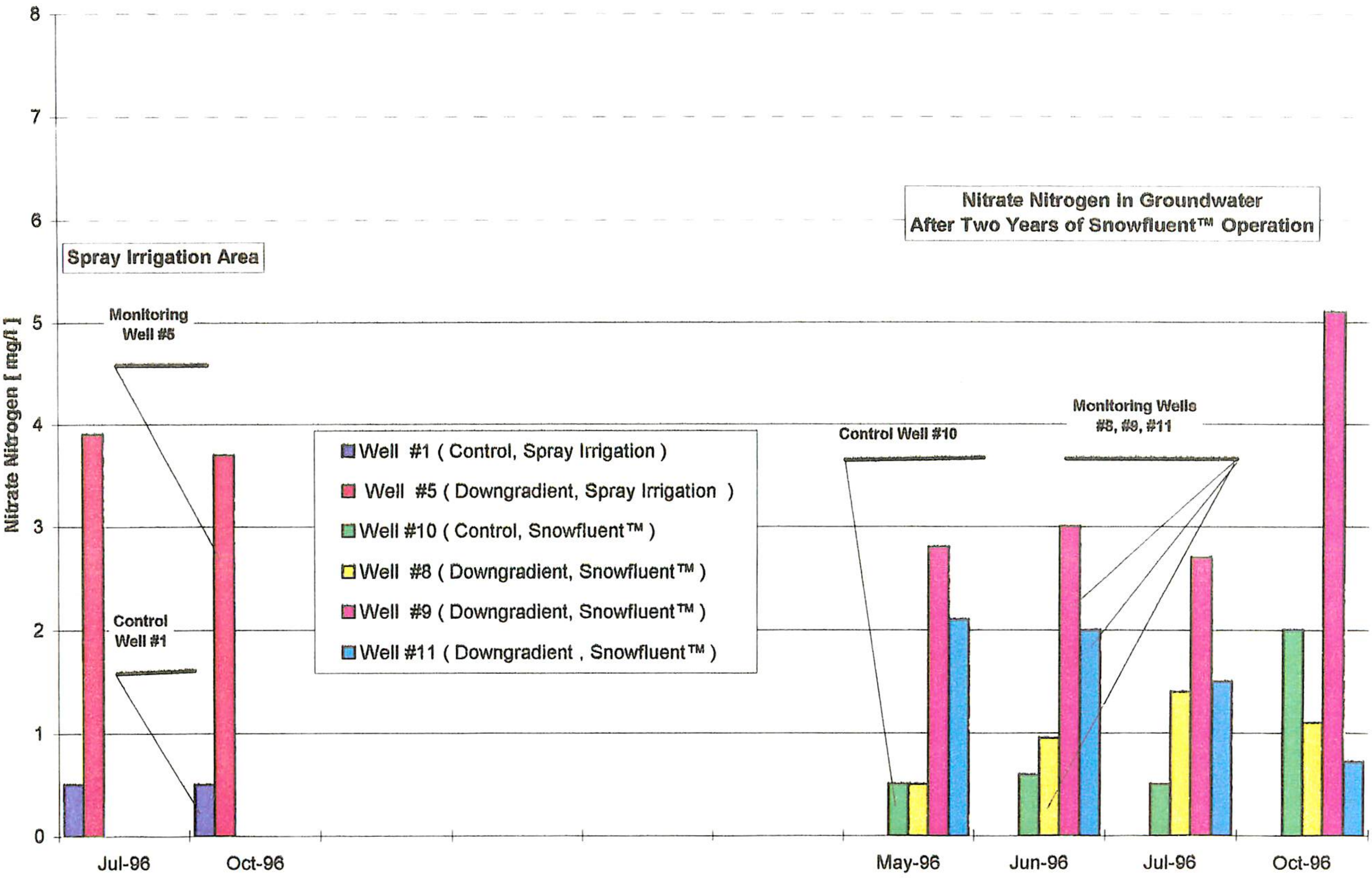
Groundwater Results
(Carabassett Valley, Maine 1995-1996)

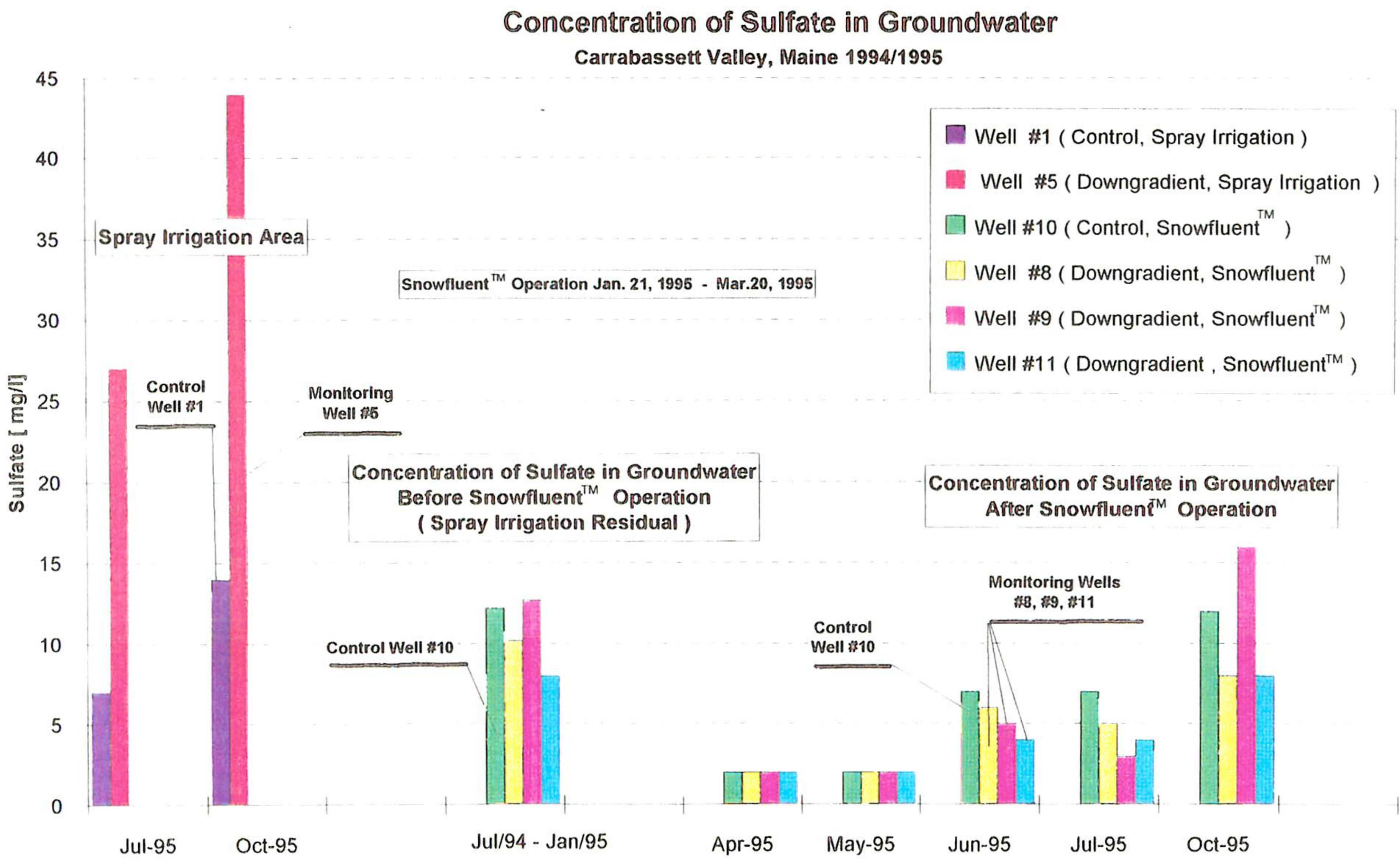

LEGEND
RUNOFF CONTROL BERM
EXISTING SPRAY IRRIGATION SITE BOUNDARY
GROUND WATER FLOW
MONITORING WELL
SNOWFLUENT TOWER
CONTROL WELL #1 (SPRAY IRRIGATION)
MONITORING WELL #5 DOWNGRADIENT (SPRAY IRRIGATION)
MONITORING WELL #8 DOWNGRADIENT (SNOWFLUENT)
MONITORING WELL #9 DOWNGRADIENT (SNOWFLUENT)
CONTROL WELL #10 (SNOWFLUENT)
MONITORING WELL #11 DOWNGRADIENT (SNOWFLUENT)
N
CONTROL WELL
MONITORING WELL #1
LAGOON 1
LAGOON 2
LAGOON 3
LAGOON 4
LAGOON 5
LAGOON 6
LAGOON 7
EXISTING PUMP HOUSE #7
MONITORING WELL #6
MONITORING WELL #7
MAIN CONTROL BUILDING
MONITORING WELL #4
EXISTING PUMP HOUSE
EXISTING SPRAY IRRIGATION BOUNDRY
MONITORING WELL #5
MONITORING WELL #2
MONITORING WELL #3
CONTROL WELL
MONITORING WELL #10
ORIGINAL SPRAY IRRIGATION AREA
TOWER #3
TOWER #2
TOWER #1
SNOW DEPOSIT AREA
MONITORING WELL #8
MONITORING WELL #11
MONITORING WELL #9
PREVAILING WINDS
TREE LINE (TYP.)
Drn: L.P.
Des:
Chk:
Sheet: 1/1
Date: 96-02-12
Date:
Date:
Scale: 1:2500
Job: CARRABASSETT VALLEY SANITARY DISTRICT
Title: WASTE WATER DISPOSAL MONITORING & CONTROL WELL PLAN
Delta Engineering
DWG File: JAN65202
Dwg.No: C-94-652-JAN
Rev: D
Rev: Date: Description By:


Concentration of Nitrate Nitrogen in Groundwater
Carrabassett Valley, Maine 1994/1995
Nitrate Nitrogen [mg/l]
0
1
2
3
4
5
6
7
8
Spray Irrigation Area
Monitoring Well #5
Control Well #1
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
Nitrate Nitrogen in Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Monitoring Wells #8, #9, #11
Control Well #10
Control Well #10
Nitrate Nitrogen in Groundwater After Snowfluent™ Operation
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Jul-95
Oct-95
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95

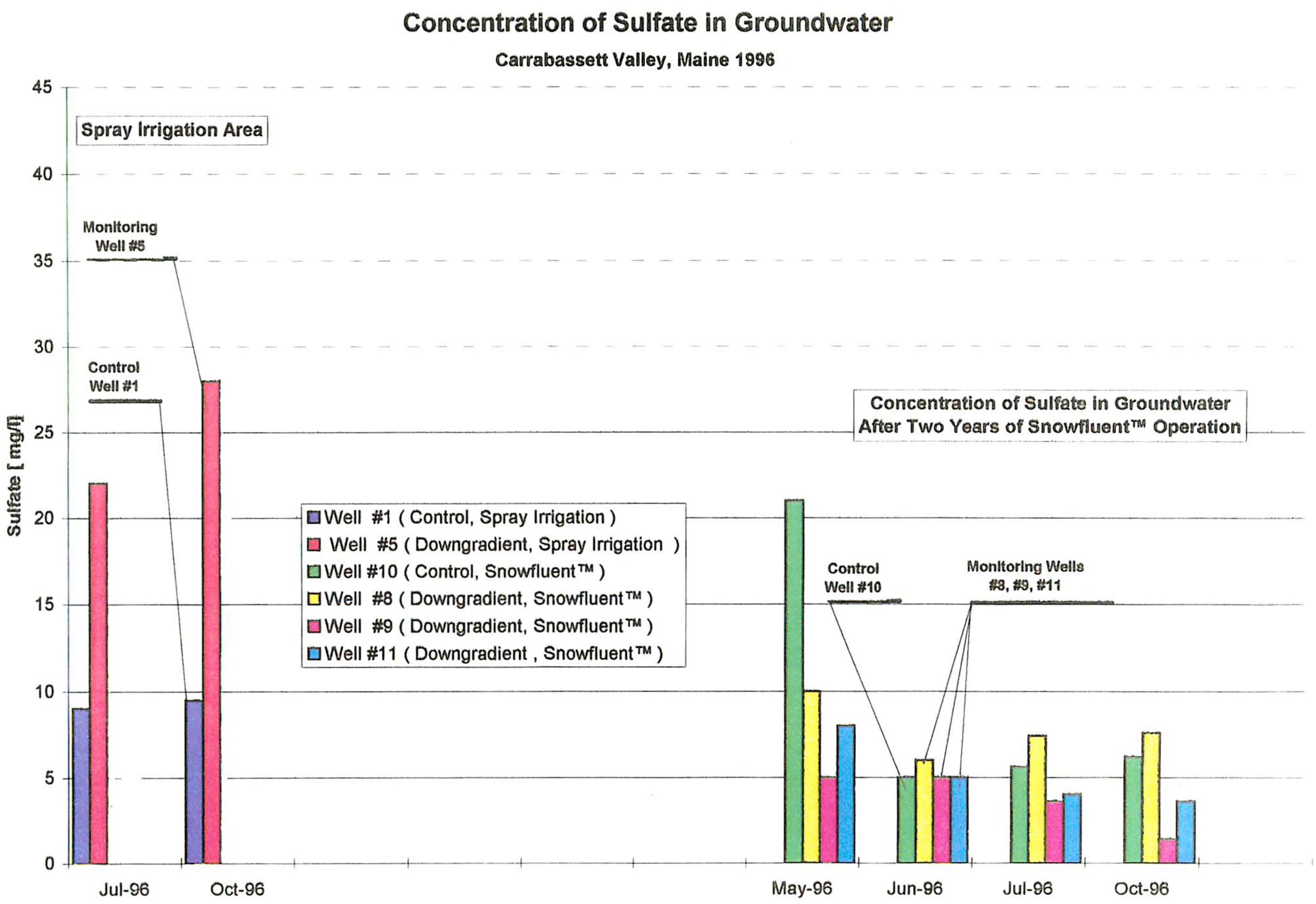
Concentration of Nitrate Nitrogen in Groundwater

Carrabassett Valley, Maine 1996

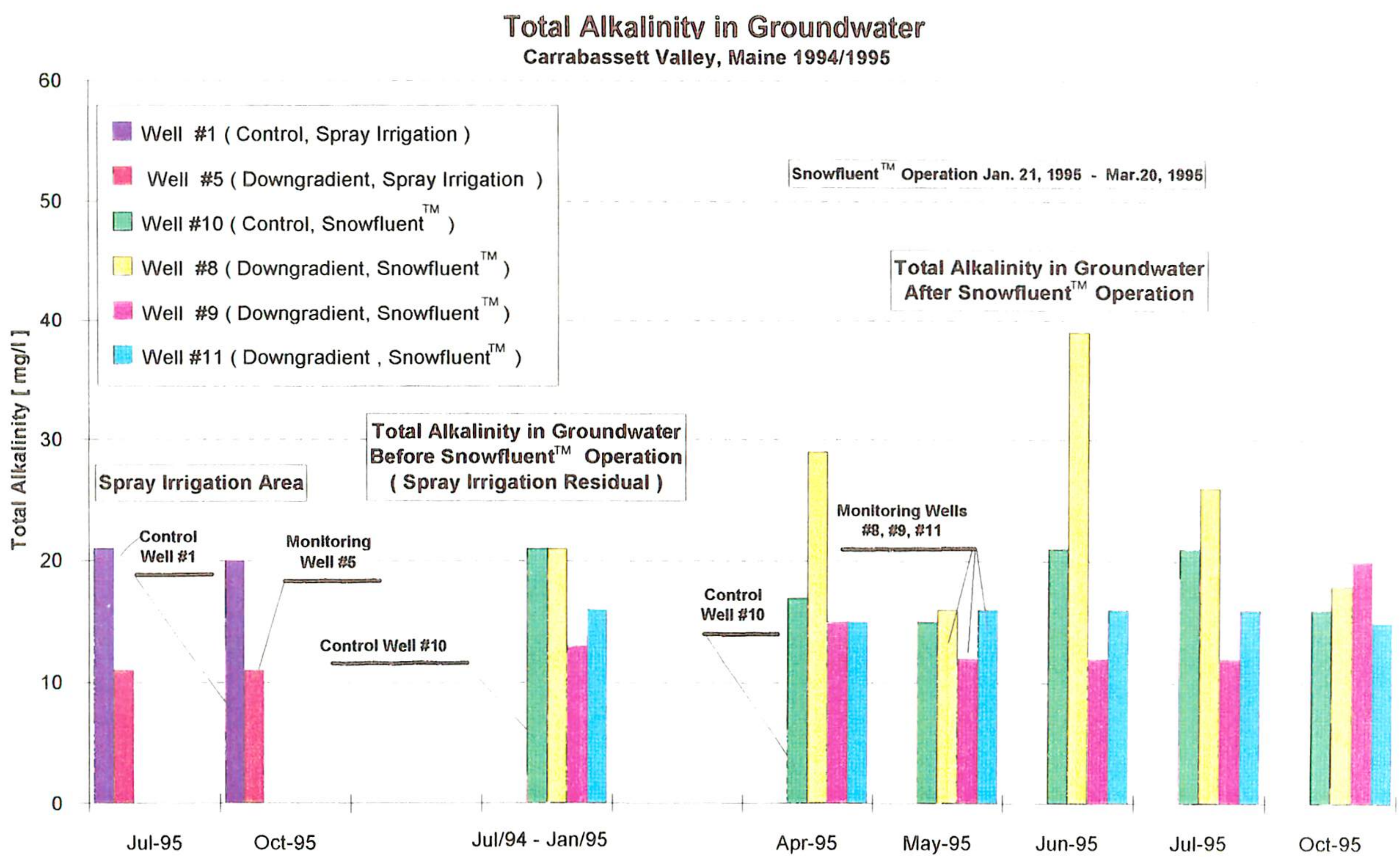


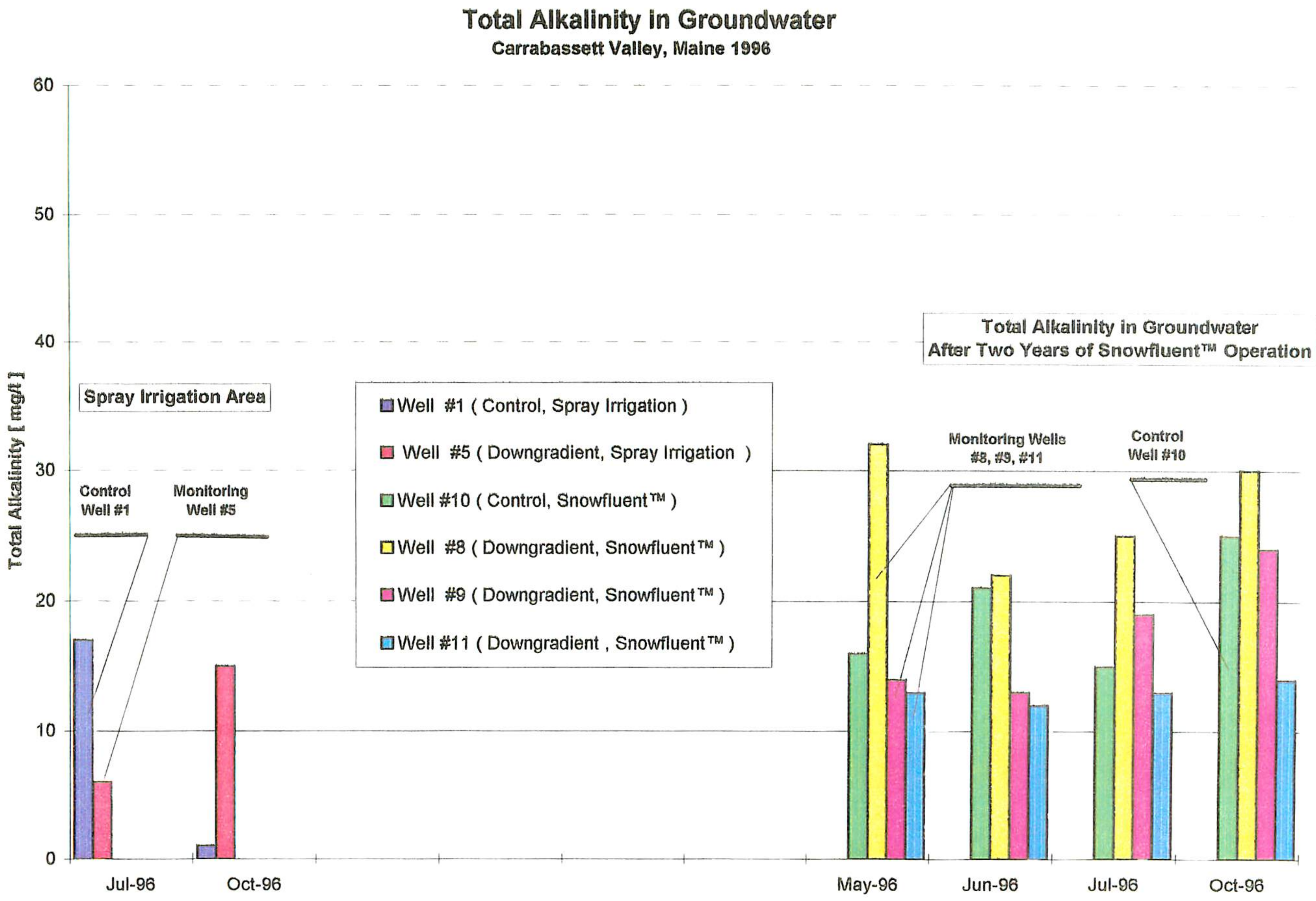


Concentration of Sulfate in Groundwater
Carrabassett Valley, Maine 1994/1995
Sulfate [mg/l]
45
40
35
30
25
20
15
10
5
0
Spray Irrigation Area
Control Well #1
Monitoring Well #5
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
Concentration of Sulfate in Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Concentration of Sulfate in Groundwater After Snowfluent™ Operation
Control Well #10
Control Well #10
Monitoring Wells #8, #9, #11
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Jul-95
Oct-95
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95

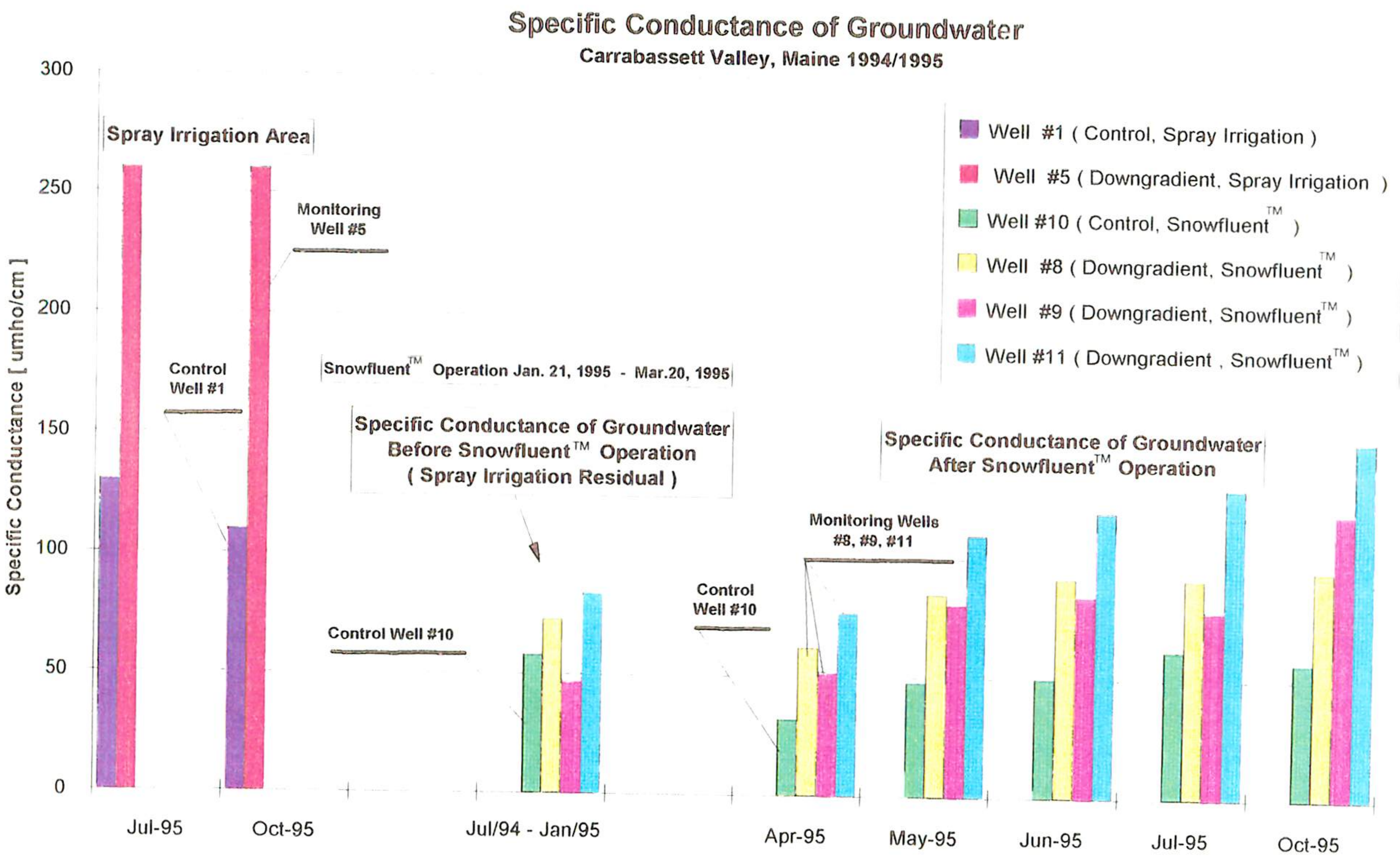


Concentration of Sulfate in Groundwater
Carrabassett Valley, Maine 1996
Spray Irrigation Area
Monitoring Well #5
Control Well #1
Concentration of Sulfate in Groundwater After Two Years of Snowfluent™ Operation
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Control Well #10
Monitoring Wells #8, #9, #11
Sulfate [mg/l]
45
40
35
30
25
20
15
10
5
0
Jul-96
Oct-96
May-96
Jun-96
Jul-96
Oct-96

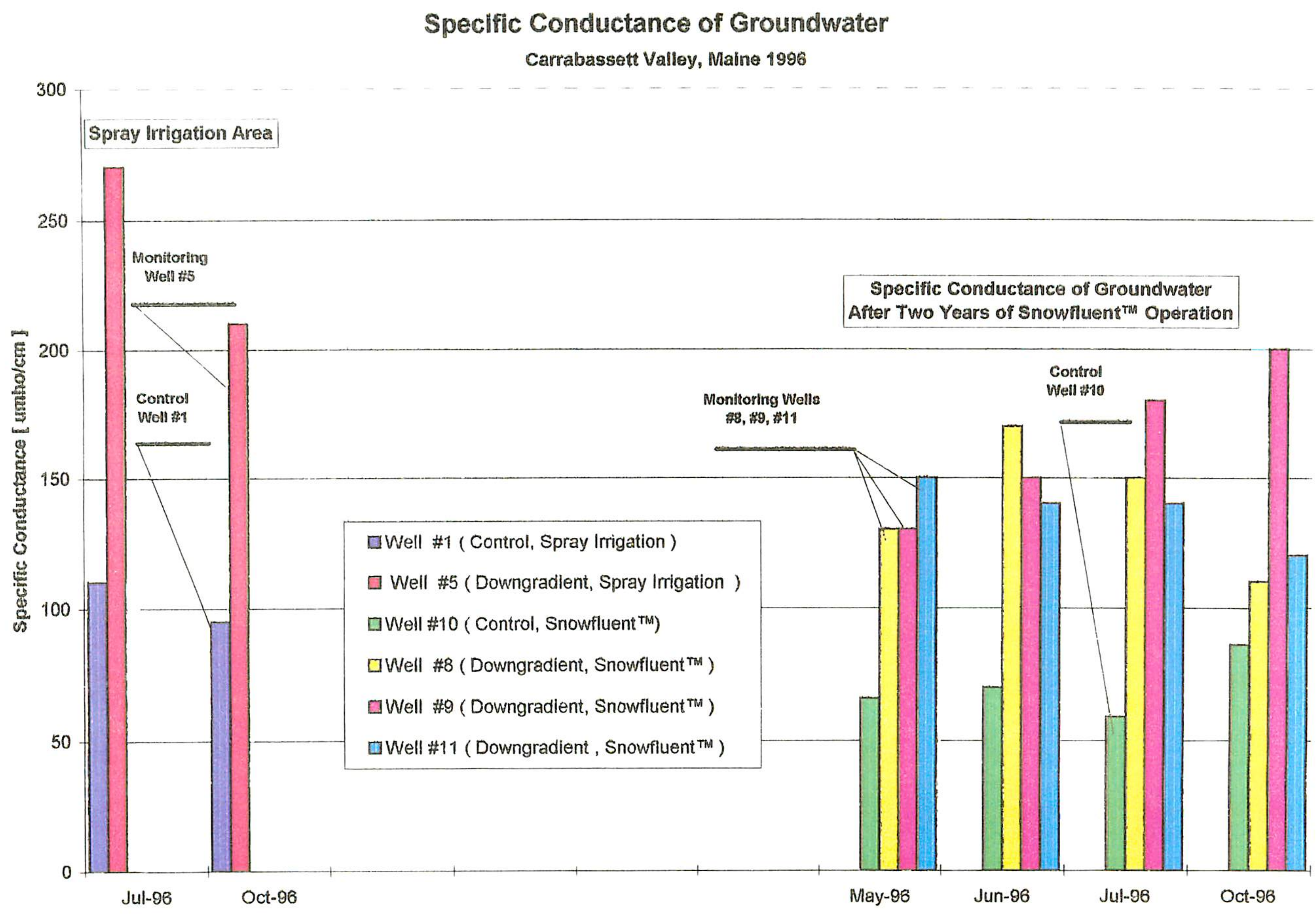

Total Alkalinity in Groundwater
Carrabassett Valley, Maine 1994/1995
Total Alkalinity [mg/l]
60
50
40
30
20
10
0
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
Total Alkalinity in Groundwater After Snowfluent™ Operation
Total Alkalinity in Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Spray Irrigation Area
Control Well #1
Monitoring Well #5
Control Well #10
Control Well #10
Monitoring Wells #8, #9, #11
Jul-95
Oct-95
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95



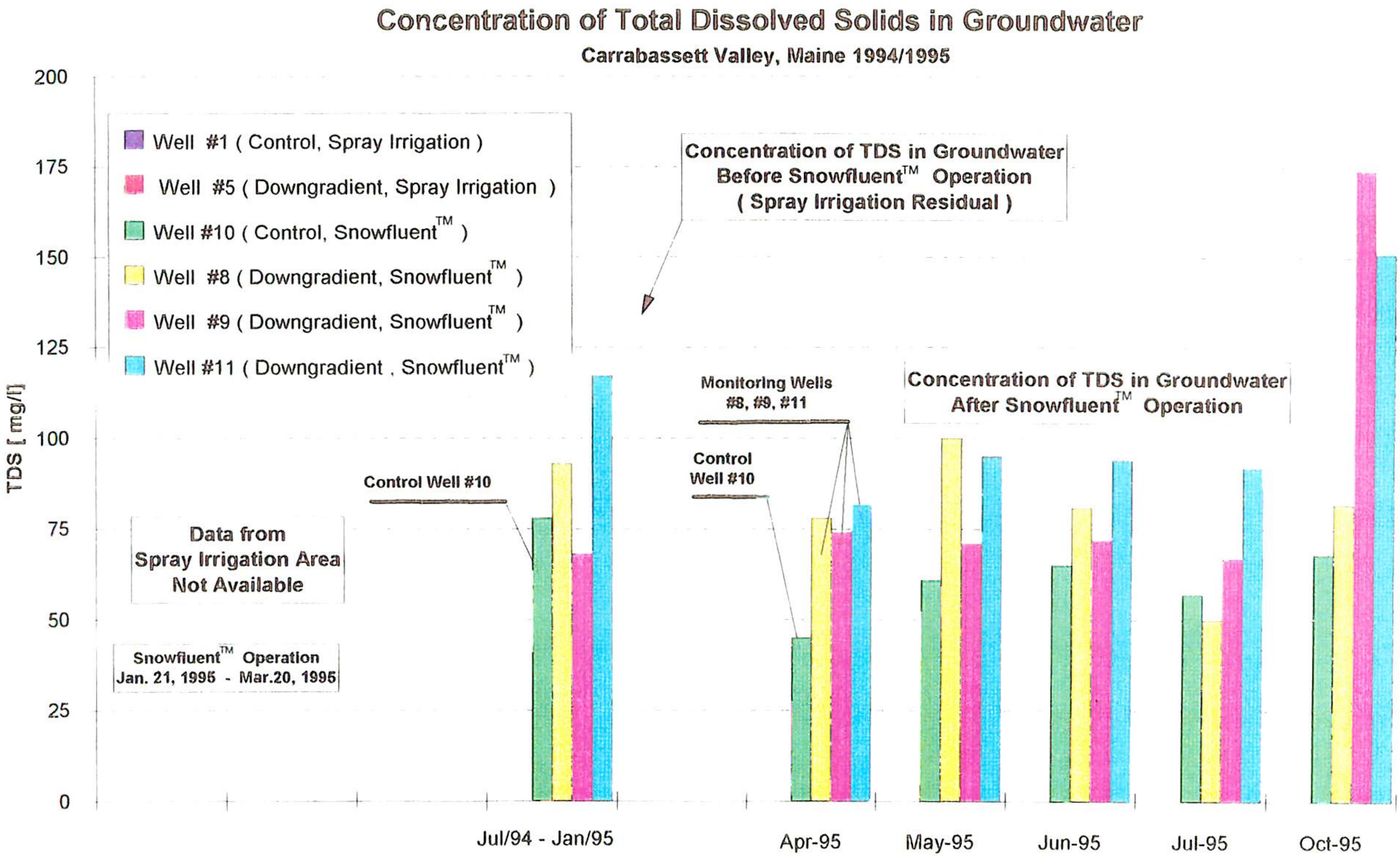
Total Alkalinity in Groundwater
Carrabassett Valley, Maine 1996
Total Alkalinity [mg/l]
60
50
40
30
20
10
0
Spray Irrigation Area
Control Well #1
Monitoring Well #5
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Total Alkalinity in Groundwater
After Two Years of Snowfluent™ Operation
Monitoring Wells #8, #9, #11
Control Well #10
Jul-96
Oct-96
May-96
Jun-96
Jul-96
Oct-96



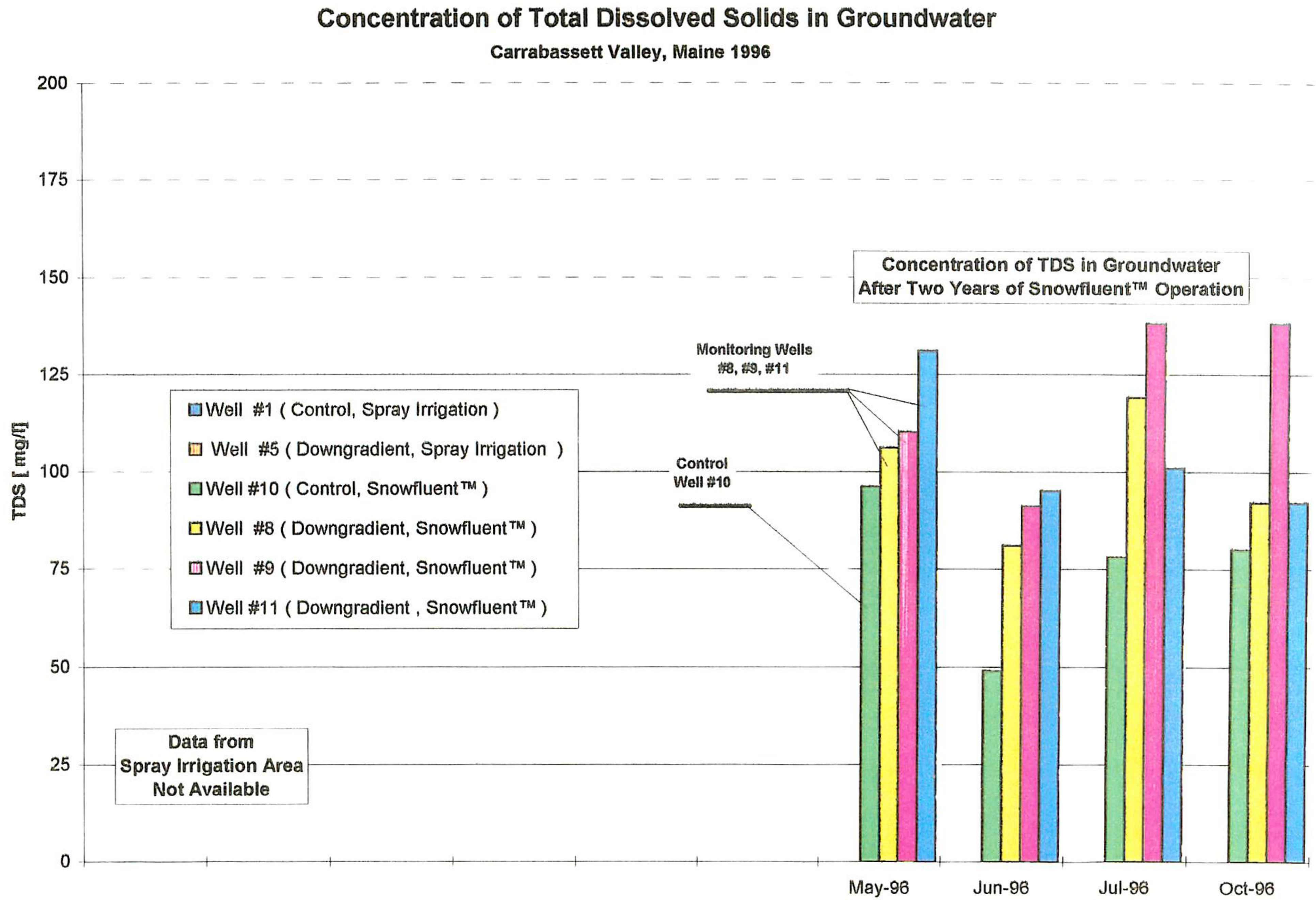
Specific Conductance of Groundwater
Carrabassett Valley, Maine 1994/1995
Specific Conductance [umho/cm]
300
250
200
150
100
50
0
Spray Irrigation Area
Monitoring Well #5
Control Well #1
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
Specific Conductance of Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Control Well #10
Control Well #10
Monitoring Wells #8, #9, #11
Specific Conductance of Groundwater After Snowfluent™ Operation
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Jul-95
Oct-95
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95



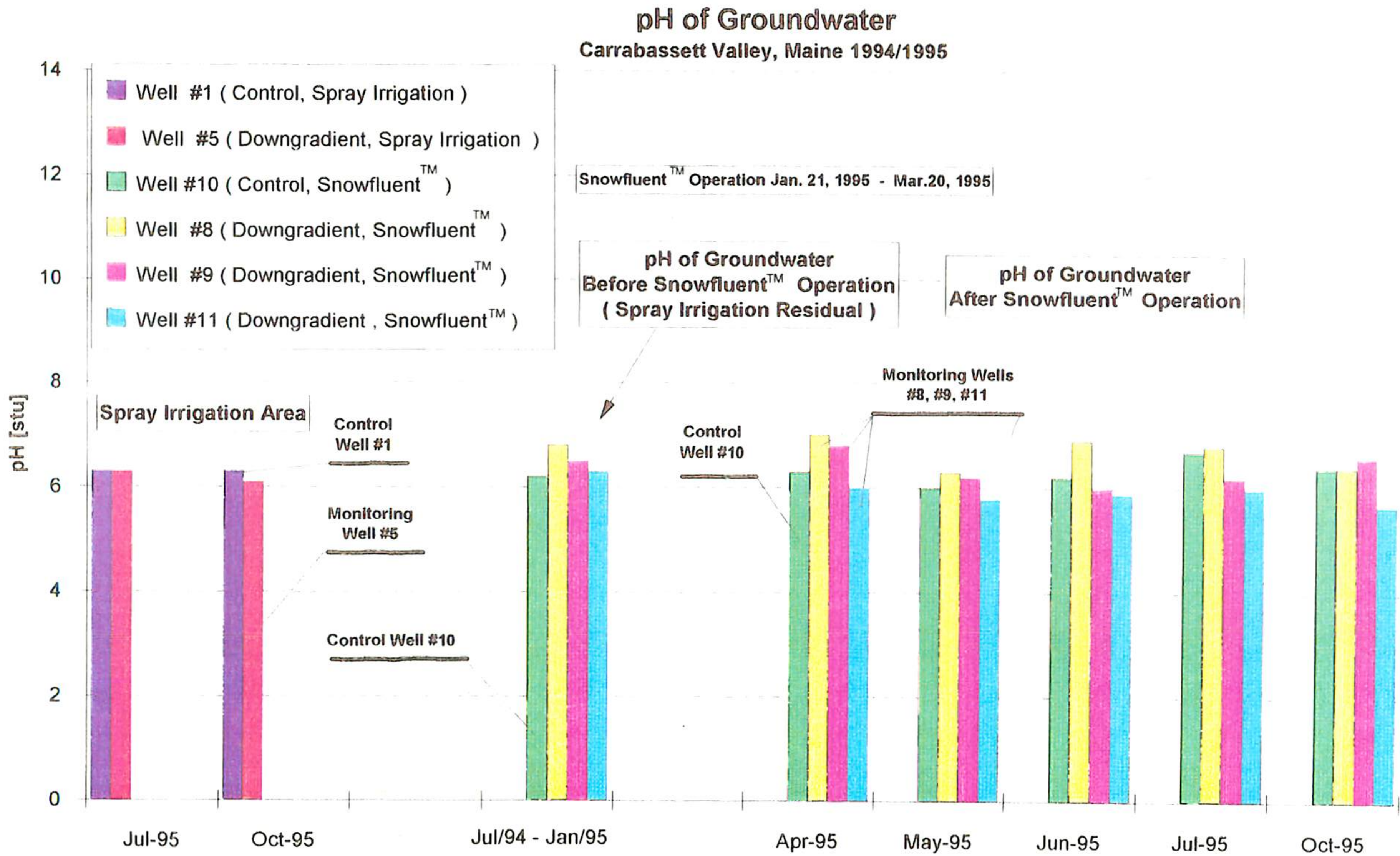
Specific Conductance of Groundwater
Carrabassett Valley, Maine 1996
Spray Irrigation Area
Monitoring Well #5
Control Well #1
Specific Conductance of Groundwater After Two Years of Snowfluent™ Operation
Monitoring Wells #8, #9, #11
Control Well #10
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Specific Conductance [umho/cm]
300
250
200
150
100
50
0
Jul-96
Oct-96
May-96
Jun-96
Jul-96
Oct-96

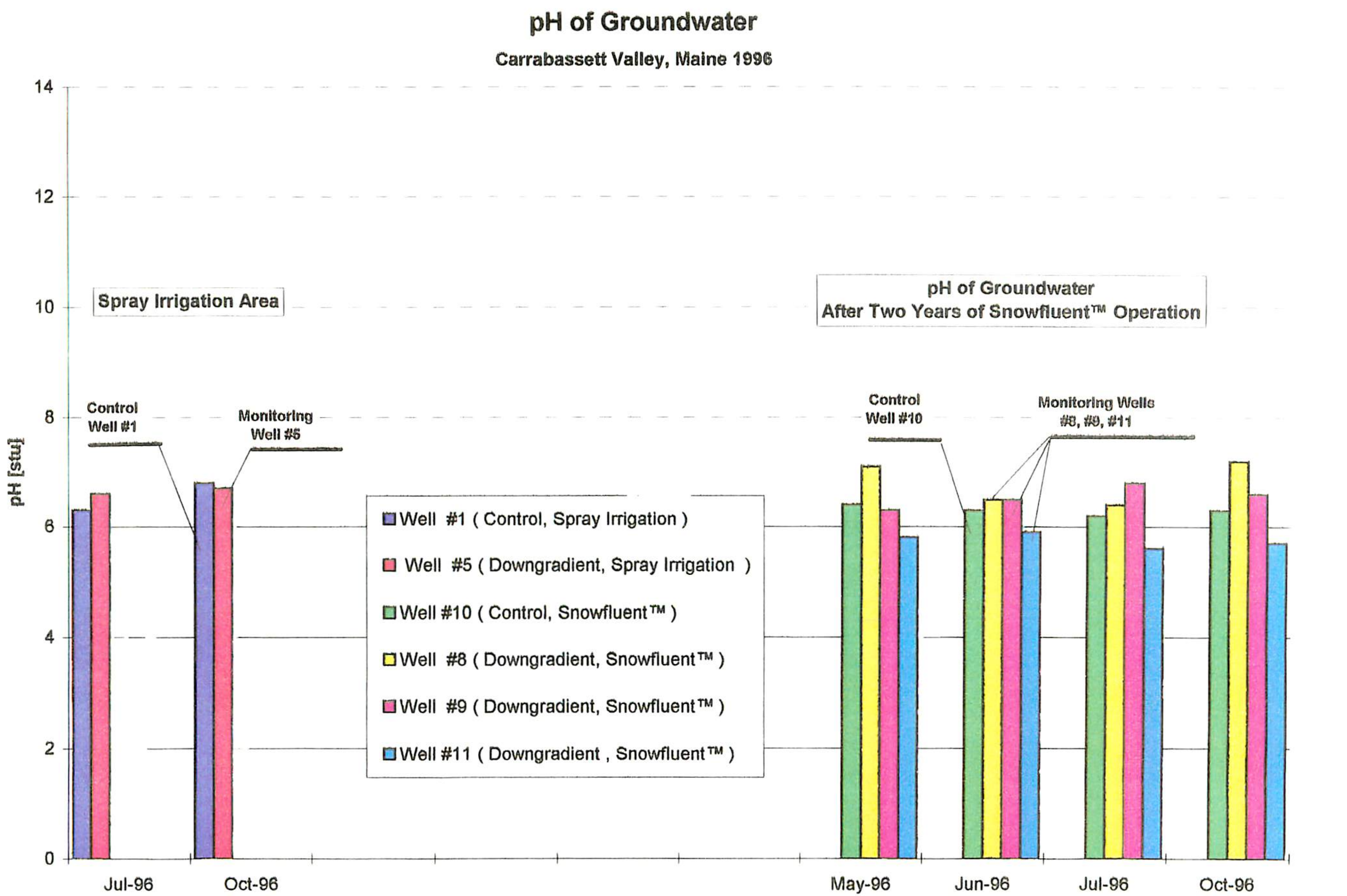


Concentration of Total Dissolved Solids in Groundwater
Carrabassett Valley, Maine 1994/1995
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Concentration of TDS in Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Concentration of TDS in Groundwater After Snowfluent™ Operation
Monitoring Wells #8, #9, #11
Control Well #10
Control Well #10
Data from Spray Irrigation Area Not Available
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
TDS [mg/l]
200
175
150
125
100
75
50
25
0
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95

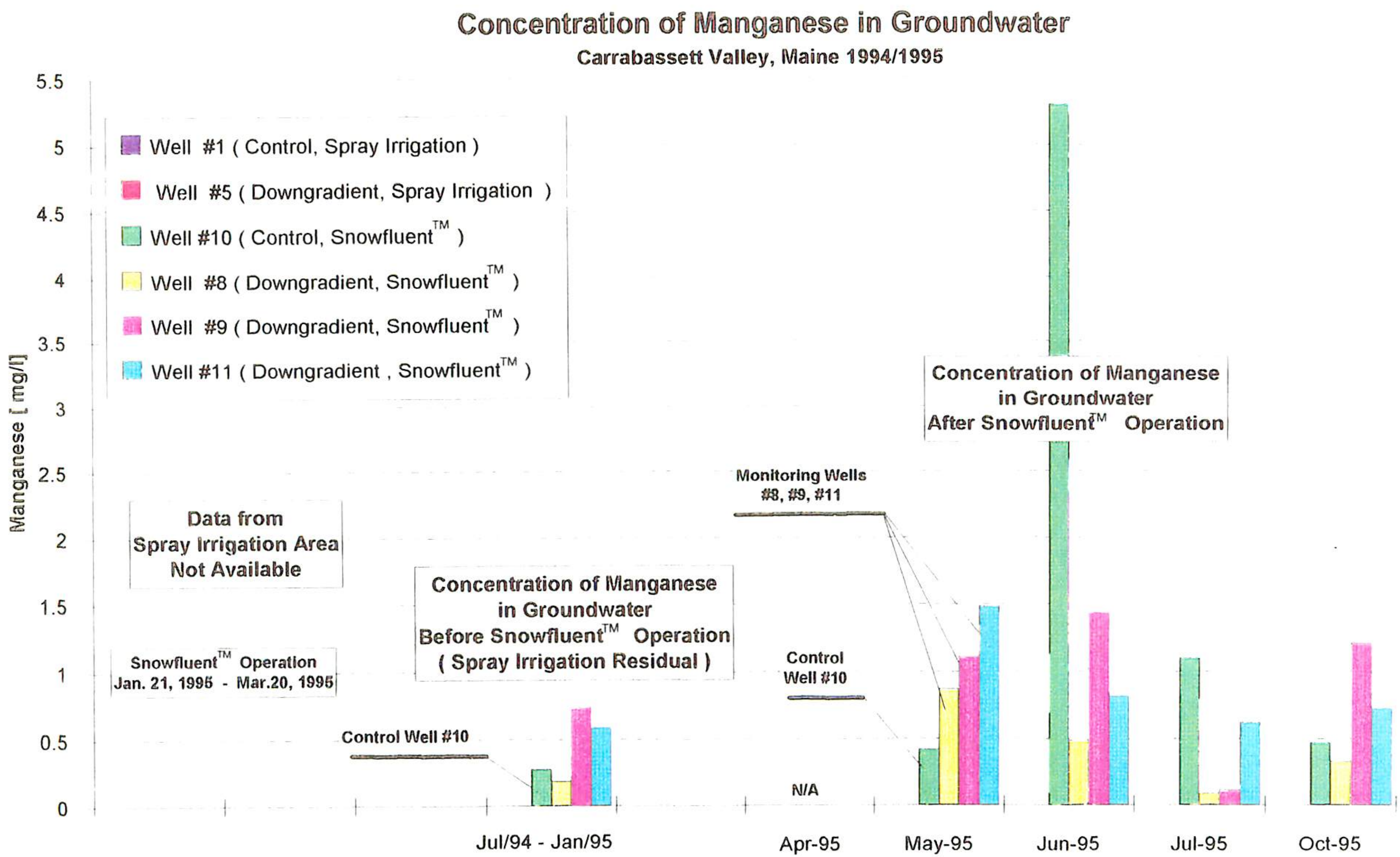


Concentration of Total Dissolved Solids in Groundwater
Carrabassett Valley, Maine 1996
TDS [mg/l]
200
175
150
125
100
75
50
25
0
Concentration of TDS in Groundwater
After Two Years of Snowfluent™ Operation
Monitoring Wells
#8, #9, #11
Control
Well #10
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Data from
Spray Irrigation Area
Not Available
May-96
Jun-96
Jul-96
Oct-96

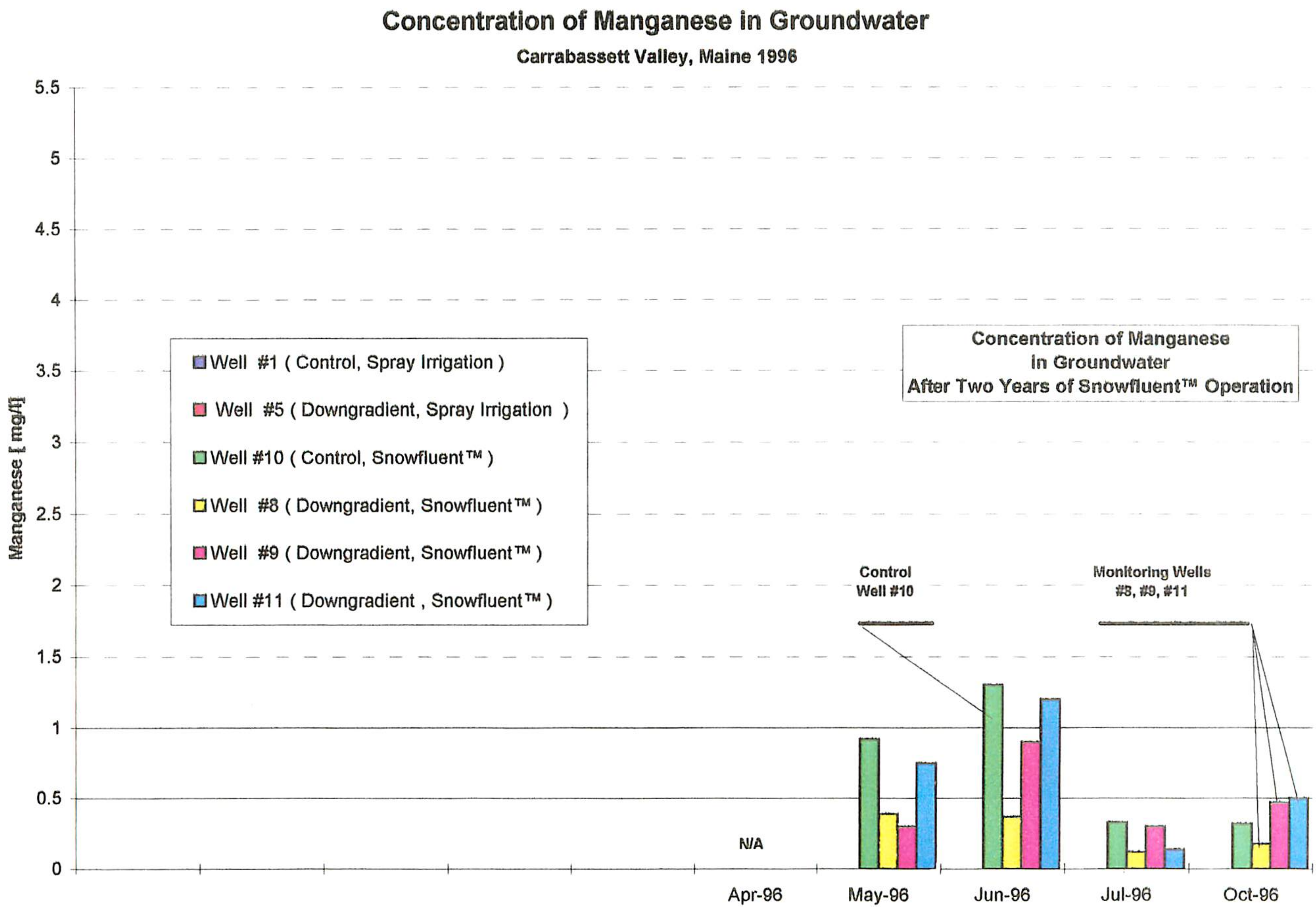

pH of Groundwater
Carrabassett Valley, Maine 1994/1995
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
pH of Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
pH of Groundwater After Snowfluent™ Operation
Spray Irrigation Area
Control Well #1
Monitoring Well #5
Control Well #10
Control Well #10
Monitoring Wells #8, #9, #11
pH [stu]
14
12
10
8
6
4
2
0
Jul-95
Oct-95
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95



pH of Groundwater
Carrabassett Valley, Maine 1996
14
12
10
8
6
4
2
0
pH [stu]
Spray Irrigation Area
pH of Groundwater
After Two Years of Snowfluent™ Operation
Control
Well #1
Monitoring
Well #5
Control
Well #10
Monitoring Wells
#8, #9, #11
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Jul-96
Oct-96
May-96
Jun-96
Jul-96
Oct-96



Concentration of Manganese in Groundwater
Carrabassett Valley, Maine 1994/1995
Manganese [mg/l]
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Data from Spray Irrigation Area Not Available
Snowfluent™ Operation Jan. 21, 1995 - Mar.20, 1995
Control Well #10
Concentration of Manganese in Groundwater Before Snowfluent™ Operation (Spray Irrigation Residual)
Monitoring Wells #8, #9, #11
Control Well #10
N/A
Concentration of Manganese in Groundwater After Snowfluent™ Operation
Jul/94 - Jan/95
Apr-95
May-95
Jun-95
Jul-95
Oct-95



Concentration of Manganese in Groundwater
Carrabassett Valley, Maine 1996
Manganese [mg/l]
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Well #1 (Control, Spray Irrigation)
Well #5 (Downgradient, Spray Irrigation)
Well #10 (Control, Snowfluent™)
Well #8 (Downgradient, Snowfluent™)
Well #9 (Downgradient, Snowfluent™)
Well #11 (Downgradient , Snowfluent™)
Concentration of Manganese in Groundwater After Two Years of Snowfluent™ Operation
Control Well #10
Monitoring Wells #8, #9, #11
N/A
Apr-96
May-96
Jun-96
Jul-96
Oct-96