7. Ecology of Beaver Lake

As was previously noted, Beaver Lake is the main water body in the Beaver Creek watershed. It is also the only historically natural fresh water body in Stanley Park. Lost Lagoon, the other fresh water body in the park, was constructed in 1916 (Steele 1988). Beaver lake has therefore long been known to play a crucial role in the overall ecology of the watershed, providing unique habitat for numerous species of plants and animals. The object of this section is to provide a brief description of this role.

From January to September 1984, a study on the Beaver Lake-Creek system was completed by Hatfield Consultants Ltd. This study assessed the biological, physical, and water quality parameters of the lake in order to determine the suitability of the system for salmonids. This information will be used to provide general information on the lake. Although there have been changes in the lake in the past 15 years, it is the most accurate data available to us at this time. There is some recent data which was collected by students from Capilano College; although, this data was collected during a single field visit, it was valuable in a number of cases.

7.1. Water quality

7.1.1. Dissolved oxygen

The most important chemical parameter in any water body is the concentration of dissolved oxygen, since it determines whether or not aerobic aquatic organisms will be able to live in the water. Every species has a threshold level of required oxygen. Both vertebrate and invertebrate communities will change if the dissolved oxygen content changes.

There are normally three main sources of dissolved oxygen: the air-water interface of the lake, primary production in the lake, and dissolved oxygen brought in by inflowing creeks. At the air-water interface, wind and wave action dissolves air into the water. Since Beaver Lake is so small and sheltered from wind, as well as often being covered with vegetation, this source of oxygen is probably not all that important. It should be

noted that species such as carp and ducks can also contribute to dissolved oxygen concentration by disturbing the lake surface. Another potential source of oxygen is lake primary production, which creates dissolved oxygen through photosynthesis. Dissolved oxygen created by photosynthesis is often important in the very top layer of a lake during the summer (Wetzel 1983). This is because there are often algae and phytoplankton blooms near the surface. In Beaver Lake, the aquatic macrophytes appear to out-compete the phytoplankton for light, so this trend is not seen.

For Beaver Lake, the majority of the dissolved oxygen originates in Prospect Creek, the inflowing creek. Prospect Creek is much higher in dissolved oxygen than the lake, as most creeks are, since there are many more waterfalls and riffles which allow the water and air to mix. From work done by Capilano college students (Lashek *et al.* 1998), it is easy to see the trend of decreasing DO as they move away from the mouth of Prospect Creek across the lake to the Beaver Creek outflow (Figure 7-1).

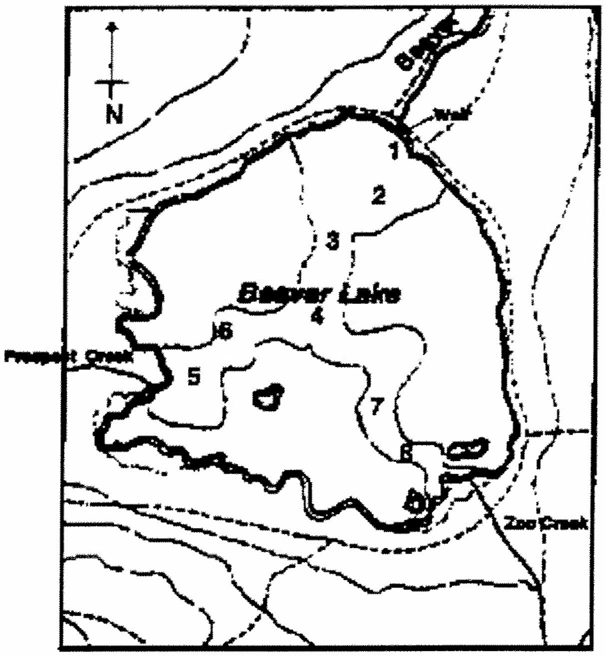

Figure 7-1 Dissolved oxygen sample sites (Lashek *et al.* 1998)

Table 7-1 Dissolved oxygen values (Lashek *et al.* 1998)

Station	Surface Dissolved Oxygen (ppm)
1	0.86
2	0.9
3	4.31
4	3.78
5	11.76
6	5.71
7	N/A
8	N/A

From Table 7-1 we can also get a general idea of the oxygen values for the lake as a whole. The most significant values are those found closest to the weir (locations 1 and 2). These are very low oxygen concentrations (~0.9ppm), especially compared to the numbers that the Hatfield report gives for the same location. The lowest monthly average reported by Hatfield is approximately 3ppm. If both data sources are accurate, they indicate a significant reduction in water quality in the past 15 years. This means that the

lake is even less suitable for salmonid habitat than it was in 1984, particularly at this location. The higher oxygen levels that Lashek *et al.* (1998) found closer to the mouth of Prospect Creek may indicate habitat which is within limits of salmonid survival requirements; however, their study was done in May. Even lower oxygen values would be expected in August.

7.1.1.1. Factors which affect dissolved oxygen

The capacity of water to absorb oxygen (and other gases) is related to the temperature of the water. The saturation concentration of oxygen decreases with temperature. This relationship is one of the factors which causes the dissolved oxygen concentration to be lower in the summer than the winter. Thermal stratification also affects the DO concentrations in some lakes.

The Biological Oxygen Demand (BOD), which is the amount of oxygen used by the organisms in an aquatic system, is also a very important factor for the DO concentrations in Beaver Lake. One of the chief contributors to BOD is organic matter. As bacteria and benthic organisms consume this organic material, they use up the oxygen in the water column and sediments. This oxygen is then not available to other organisms such as fish. Since Beaver Lake produces a lot of organic material, the BOD is fairly high. The highest BOD in Beaver Lake probably occurs at the sediment/water interface. This is because Beaver Lake produces more organic material than it decomposes, resulting in a net sedimentation on the lake bottom. This gives rise to a large benthic oxygen-using community. For the summer of 1984, Hatfield found that there was an average of 12,000 macrobenthic organisms per square metre of substrate.

7.1.2. Temperature

The highest temperature recorded by Hatfield was 18.5 °C, which occurred in August. In their work in May 1998, Lashek *et al.* (1998) recorded a high temperature of 15.5 °C. This value is quite high considering how early in the season the work was done. This may be due to the fact that 1998 was an exceptionally warm summer.

7.1.3. Other factors

Hatfield (1984) tested the lake water for a number of other water quality characteristics and found them to be within the ranges acceptable for salmonid survival. These characteristics included pH (~6.1), alkalinity (12-16 mg/L $CaCO_3$), hardness (soft water) and nonfilterable residues (mostly $<$25mg/L), as well as phosphorus, nitrogen, and silica compounds.

7.2. Anaerobic respiration

When the amount of dissolved oxygen is very low, anaerobic respiration takes over as the primary type of metabolism. Organisms which respire anaerobically use other molecules besides oxygen as their electron acceptor and produce things besides CO_2. An important product in Beaver Lake is hydrogen sulphide (H_2S) gas, which is produced in the sediments of Beaver Lake. The importance of this gas is in its toxicity to many species. According to Hatfield, the levels of H_2S do not appear to be significant ($<$0.01mg/L), except perhaps in the winter when the lake was frozen over while anaerobic respiration was ongoing in the sediments. We noticed a rotten egg smell while we were on the lake taking our core samples. The smell seemed quite strong, so perhaps the H2S levels have risen in the last 15 years. This is something which could perhaps be investigated by another project. Another product which may be important is methane (CH_4) gas, but no one has done measurements of this.

7.3. Macrophytes

Macrophytes are described by Wetzel (1983) as large aquatic plants. They often include seaweed, as well as the vascular aquatic plants which are most important in Beaver Lake. In their report, Hatfield includes a map of the vegetation cover on the lake surface (Figure 7-2). Although this information may be slightly outdated, it gives us an idea of what species are predominant. The introduced white water lily (*Nymphaea spp.*) covers approximately 50% of the surface area. The yellow water lily (*Nuphar sp.*) also covers a significant area of the lake and the small lily called water shield (*Brasenia schreberi*) is interspersed on the surface. Buckbean (*Menyanthes trifoliata*) is another aquatic macrophyte which covers a large area of the lake. The *Nymphaea* species are not

native to this area, so their presence in the lake can be directly associated with the water lily introduction of 1936. All the other species of macrophytes can be found in the area, so it is harder to determine if they are truly native to the lake or were also introduced. Buckbean is the exception to this as it is very unlikely to have been introduced. The introduced water lilies are commonly blamed for increasing the sedimentation rate, and therefore the infilling of the lake. Although we found that the overall sedimentation rate has increased in the past 100 years, it does not appear to be as great of an increase as was formerly thought. The inorganic sedimentation rate plays a much larger role than was believed to be the case.

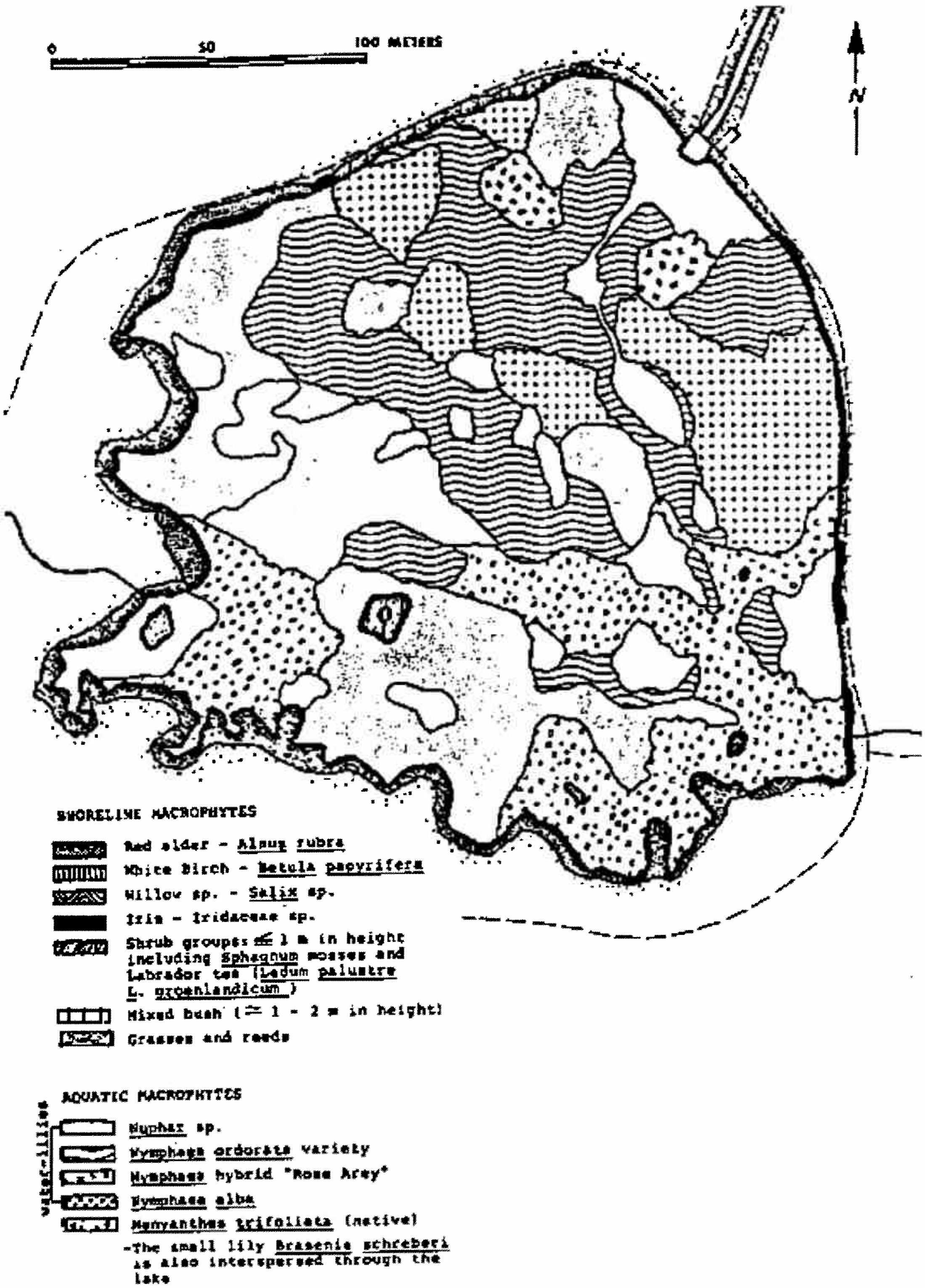

Figure 7-2 1984 Vegetation on Beaver Lake (Hatfield Consultants 1984)

8. The "natural" basin.

This section is intended to be a short description of what the watershed might look like in the absence of human interference and is focused on putting aside some misconceptions about the watershed.

The hydrology of the basin would be similar except the creek would stop flowing for about two months during the summer and the lake would drop in height during this time. The stream flow recession might be slightly slower than is presently the case as there would be no trails, ditches or artificial creeks increasing the channelization of the basin. The lake itself would be lower at times of peak runoff than is presently the case as the weir would not exist. In addition to this the total amount of water flowing out of Beaver Creek during a year would be at least four times less than is presently the case

The depth of the lake would at best be only slightly deeper than is presently the case. The raising of the water level has roughly equaled the human induced sedimentation in the lake, such that the depth of water in the basin has remained relatively constant. However, the area of the lake would likely be larger. The elimination of creek flow during the summer months would cause the lake to become warmer and more anoxic. Fish would be infrequent visitors to the basin and only very marginal populations would survive in the streams and lake. The carbon to nitrogen ratios indicate that the lake would be dominated by aquatic macrophytes as is the case today. The species would be different, and there may be slightly less of the lake covered by these species, but the majority of the sediment in the lake would come from the aquatic vegetation.

The forest would be dominated by mature coniferous forest and there would be very little inorganic sediment entering the lake. The vegetation around the lake edge would likely be more typical of a wetland which goes through seasonal drying and wetting periods, and there may be more extensive areas of bog.

Having said all this, it is important to realize that in general the human impacts of the basin have left the system relatively intact and succession still dominates the

landscape. This is a significant achievement given the basins location within the city of Vancouver.

9. Integration of results: summary

This section provides a summary of the major interactions that we attempted to look at in the Beaver Lake system (Figure 9-1).

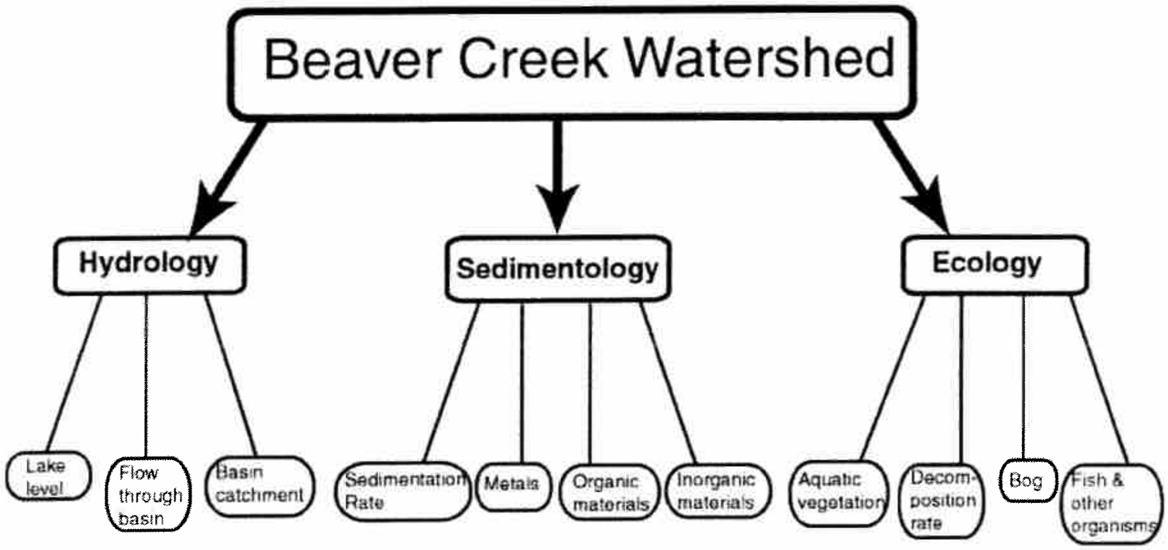

Figure 9-1 Interactions within the Beaver Creek watershed

9.1. Lake level and vegetation

The water level and degree of seasonal fluctuation will have an impact on the degree of encroachment of terrestrial vegetation. In Beaver Lake, fluctuations in the lake level is nearly eliminated by the addition of city water to the system. Without this, the lake level and stream flows would be significantly reduced during the summer season. This lake level reduction would result in exposed soil which allows the encroachment of more terrestrial species of vegetation. The computer model indicates that the reduction would begin in June most years if the city water was completely eliminated. This is a time of year when plenty of plant species are flowering, making colonization very likely. The encroachment rate will increase the earlier the lake level is reduced and the longer it stays reduced.

9.2. *Lake level and bog*

The unique Sphagnum bog system which is found on the eastern side of the lake will also be affected by the lake level fluctuations. The bog area likely shrunk in area due to flooding when the lake level was raised early in the century. It is hard to say how exactly the bog would be affected. Allowing the lake level to fluctuate could potentially increase the bog area since the area would no longer be flooded all year. The main threat to the bog area is currently the encroachment of more terrestrial species. So it is also possible that allowing the lake level to fluctuate will actually cause a decrease in the bog area.

9.3. *Lower flows through Beaver Lake and fish*

A decrease in the volume of water flowing through the basin is going to decrease the mixing of the lake. With a decrease in the mixing of the lake, the levels of dissolved oxygen will decrease and this will impact the fish. How much the water has to be reduced in order for the lake to become uninhabitable for fish is unclear. If the lake receives no water for a period of a couple of months, which is what the model predicts, then it is unlikely most fish could exist in the lake, especially oxygen sensitive fish such as Cutthroat trout and Coho salmon.

Reduced flow through the lake also impacts the temperature regime which is of critical importance to the fish. A reduction in the water supply may cause the lake to become warm enough from solar heating that most fish would not survive. Some temperature resistant fish such as carp may continue to exist.

9.4. *Lower flows in Beaver Creek and fish*

The water flowing through Beaver Creek is clearly important for the fish which live in that water. The flow in the creek creates the fish habitat, supplies the food, and keeps the water cool and aerated. In the creek the temperature problem is associated with the supply of warm water from the lake rather than solar heating. The low flow condition, where the water flows completely through the subsurface, could actually be beneficial for the fish if we ignore the consequences of low flow in the lake. As long as there are deep enough pools for the fish to live in during the periods of low flow, the

gravel would cool the water as well as aerate it as the water flowed through the subsurface. There would also have to be a significant amount of subsurface flow in order for this to be feasible.

In general creeks do not have the same problem with aeration as the flow is always turbulent and mixes with the surface. Having said this it is possible to increase the oxygen content in creeks by increasing the mixing of the water with the atmosphere. The fish in the creek are more dependent on the quality of water coming into the creek than they are on the actual amount of water in the creek.

9.5. Sedimentation rate and lake level

Both the organic and inorganic sedimentation contribute to the overall sedimentation on the lake bottom. This sediment slowly decreases the lake level. The sedimentation rate is very important as it provides an estimate of the time it will take the lake to fill in. We found the sedimentation rate to be approximately $0.57 kg/m^2/yr$.

9.6. Aquatic vegetation and organic sedimentation

The aquatic vegetation is a significant contributor to the overall sedimentation rate in the lake. The leaves die off at the end of the growing season, and since they do not decompose fully, they accumulate on the bottom of the lake. This results in the low density organic sedimentation which has been blamed as the major contributor to the sedimentation rate. We found that our cores were composed of approximately 40% organic and 60% inorganic near the surface.

9.7. Sedimentation and decomposition rate

The decomposition of organic substances is carried out by a number of different lake organisms and the rate of this process is determined by a number of different factors including the temperature and oxygen levels. Since the oxygen concentrations are higher in the water column, a deeper lake level results in a faster initial decomposition rate. The process continues in the sediments, but it is much slower because of the anaerobic conditions. The plant material which does not get decomposed results in sedimentation

on the bottom of the lake. It would be interesting to find out the actual decomposition rate of the Beaver Lake sediments.

9.8. Catchment basin and inorganic sedimentation

The vast majority of the inorganic sedimentation entering Beaver Lake originates in the catchment basin and runs in as a result of stormflows. This inorganic sedimentation is approximately 160 times what it was before the trails and roads were built through the watershed. This is much larger than the increase of approximately 10 times seen in the organic sediments, leading us to believe that the sources of inorganic sediment are more important to deal with than the organic sources.

9.9. Catchment basin and metal contaminants

The runoff from the causeway results in metal contaminants entering the Beaver Lake system. We found that there was a very distinct increase in the metal concentrations in the sediment record. By correlating the depth of this increase to the time when the causeway was completed, we can use the metals to estimate the sedimentation rate in the lake. The metal contaminants in Beaver Lake were not found to be at high enough levels to be considered dangerous to wildlife, but if they continue to enter the basin, they could accumulate. The oil-water separators which are to be installed with the causeway expansion are a good way of dealing with this problem.

10. Framework and values

Taking into account the principles of ecosystem management, the state of the watershed, and our own ideas and concerns, we feel it is necessary to state a set of values on which we base our recommendations. We also believe that in order to make effective value judgements it is necessary to specify the framework within which the ecosystem exists. First, this watershed is an urban watershed existing within a park. The watershed is therefore subject to influences and stresses that would not be present elsewhere. For example, there are roads running through the basin that receive continuous use. Trails have been constructed throughout the watershed for the many people who visit the area each day, the public. Not only does this public visit the watershed but also, in many cases, cares about the future of the watershed and has opinions regarding how it should be managed. The public has considerable influence regarding the management of the watershed because without them, the park itself would find it difficult to exist. We believe that value judgments and management decisions made outside of this context will not be sustainable. Recognizing therefore that we are working within this framework, we value the following things:

- **ecosystem processes occurring within the watershed, specifically the process of natural succession**

  We believe that processes occurring within the watershed, although influenced by humans, have retained basic qualities that would exist in a system removed from human influence. That is to say, all lakes move through a successional process from lakes to terrestrial ecosystems. We recognize this process as being paramount to the idea of preserving the ecosystem in its current state, i.e. as a lake.
- **educational/interpretive programs**

  We believe there are many educational opportunities within the Beaver Creek ecosystem and that relating this information to the public is crucial to the survival of the ecosystem. More specifically, we believe that successional patterns themselves hold great interpretive value. These processes have shaped much of Canada's

landscape and the Beaver Creek watershed presents a unique opportunity for the public to learn about these processes "in their own backyard".

- **recognition of past and present human impacts**

  We think it is important to recognize past impacts humans have had on the watershed as well as the ongoing human impacts on the system. To manage the watershed effectively today, we must understand and recognize the historical and current role of human interaction. Recognizing the role humans play in the system, including the disturbances they create, is also a valuable educational tool.

- **responding to past human impacts**

  While we value the process of succession in the Beaver Creek watershed, we also believe it is important that succession due to human impact does not proceed at an alarming rate. We have sped up the process of succession and as a result, completely pulling out of the watershed (i.e. turning the water off) will result in a rapid transition to a terrestrial ecosystem of some form.

- **goals of BLEEP**

  The group values the goals of the Beaver Lake Environmental Enhancement Project as a means of public input into the management of the system. BLEEP has developed a set of goals and objectives based what they believe to be the most important issues within the watershed. We respect these goal and believe they are important in ensuring that any decisions made are sustainable.

- **limit future impacts**

  We believe it is important now to limit any other major human disturbances within this watershed. We believe it is important to interfere with the current system as little as possible, keeping in mind all values stated above.

11. Recommendations

11.1. Recommendation #1: Do not dredge the lake

Dredging portions of Beaver Lake has been proposed as a potential solution to the sedimentation problem. This solution would be an effort to stop the succession process occurring in the lake. In addition, questions arise as to whether this solution would be effective in prolonging the life of the lake.

11.1.1. Scientific evidence

Sedimentation rates calculated based on estimated dates within the sediment cores show that previous studies have overestimated the speed of this process. The sedimentation was previously thought to be mainly organic, but our data have shown a large inorganic sediment source. This problem can be addressed without dredging the lake. Dredging itself may not be effective in extending the life of the lake as only portions of the lake would be dredged, creating channels. A similar system of channels would exist in the lake even if dredging were not carried out. As the organic layer makes up a relatively small portion of the sedimentation, the inorganic material (silts) in the lake would have to be dredged in order for the dredge to be effective. Dredging the lake increases the possibility for heavy metals in the lake to become resuspended and therefore more available for uptake by plants. Lastly, dredging the lake would cause a huge disturbance to the entire ecosystem.

11.1.2. Logistics

Dredging the lake would entail a large capitol expense and would require maintenance and continuous funding over time. The issue of heavy metals and the possibility of resuspension would need to be researched and dealt with in greater detail. The dredgeate would need to be deposited somewhere and restrictions on heavy metal concentrations will likely limit available options. Lastly, the lake is not readily accessible to the heavy machinery required in dredging the lake.

11.1.3. Values

This solution does not allow the process of natural succession to occur. It creates a large human disturbance over the entire ecosystem.

We do not believe dredging Beaver Lake to be a viable option for management of the basin. Dredging would drastically alter the current system and there are doubts with regard to how effective a dredge would be. It is logistically difficult and goes against one of our main values, that of allowing ecosystem processes to occur.

11.2. Recommendation #2: Reduce the inorganic sedimentation rate

The inorganic sedimentation rate is causing problems for both Beaver Lake and Beaver Creek. A decrease in the supply of inorganic sediment could reduce the sedimentation rate in Beaver Lake by 50 % and create much better fish habitat in Beaver Creek.

11.2.1. Scientific evidence

The sediment cores showed that the inorganic sediment has increased from being about 15 % to 60 % of the sediment. This increase has direct implications for the sedimentation rate in Beaver lake. If the inorganic sediment supply was controlled and returned to about 15 % the sedimentation rate would be cut in half. In Beaver Creek a reduction of gravel in the stream would enable scour to occur at bends and around pieces of LWD to create pools along the stream. These pools would create fish habitat within the creek.

11.2.2. Logistics

The supply of gravel for the creek comes from the fill used in the restoration work and from the trails along the channel especially from around the weir. The supply of gravel could be reduced by better management of storm runoff along ditches and through, rather than over the weir.

The source of the inorganic sediment filling in the lake is not know, and as such limiting the supply of sediment is not immediately possible. The sediment appears to

come from the lake edge and most likely comes from both the trails in the park and from dust on the causeway. The trails could be board walked or reconstructed with French drains and geotextiles to control the supply of sediment off the trail surfaces. Both the runoff from the trails and from the roads could be run through settling ponds with geotextiles in place to collect silt. This process, especially the resurfacing of the trails, may be expensive.

11.2.3. Values

A reduction in the supply of sediment would be in accordance with our values as it would not be a huge disturbance. It would recognize the presence of human impacts and would be an attempt to limit the impacts. It would help to reduce the sedimentation rates and increase the longevity of Beaver Lake, this would coincide with the goals of BLEEP.

A reduction in the supply of inorganic sediment seems to be a feasible, relatively easy solution which would benefit the system. Geo-textiles might be a better solution than boardwalks to be used in resurfacing the trail surface as using these would leave the trail relatively unchanged. Cyclists are likely to be apprehensive about the introduction of boardwalks in place of trails as they will be slippery to ride on. A set of settling ponds would further reduce the supply of silt to the lake. Similar efforts could be used to control sediment supply to the creek.

11.3. Recommendation #3: Develop an interpretive program relating to ecosystem processes within the Beaver Creek watershed.

Interpretive programs within parks serve to educate the visiting public about the area. A good interpretive program gives visitors the opportunity not only to enjoy the beauty of the area, but to learn about the system and processes governing its existence. It provides a medium to present interesting historical information as well as current issues surrounding the park. Interpretive programs may play a crucial role in public involvement in the area.

11.3.1. Scientific evidence

It is clear that succession is occurring in this ecosystem. Beaver Lake will eventually be filled in and will progress toward a terrestrial ecosystem. There are many interesting processes taking place that accompany this transition. Through our research, we have uncovered some very interesting information with regard to the historical record of sedimentation in the basin as well as ideas as to what the basin may have looked like historically and what it would look like if human influence were eliminated. Furthermore, the presence of a freshwater ecosystem in an urban setting is rather unique. Therefore, emphasis on this ecosystem while it still exists and on its natural progression toward a terrestrial ecosystem is an invaluable educational tool. Finally, it is important to educate the public regarding the impact people have had on the basin in the past, and the continuing influence that we exert on it.

11.3.2. Logistics

This recommendation would be relatively inexpensive. It requires the basic design and implementation of an interpretive program. One major requirement is creative minds to put the program together. Mirror Lake in Yosemite National Park may be able to serve as a template.

11.3.3. Values

This recommendation acknowledges past and present human impacts on the system. Recognition of these impacts would form an integral part of the interpretive program. Making people aware of past human disturbances as well as ongoing impacts that they are a part of allows us to understand humans as part of any ecological system. The recommendation emphasizes the education/ interpretive values we have previously cited as being crucial to this urban watershed. Designing and implementing such a program would not create a large disturbance on the system and responds to BLEEP's goal of maintaining and enhancing the educational value of the watershed.

Implementation of an interpretive program would enhance the public's understanding of ecological processes, both in terms of aquatic systems and successional patterns. In addition, it would help people to learn about and understand the role humans play within these ecosystems.

11.4. Recommendation #4: Decrease city water supply

In order to achieve a hydrological regime that resembles the one described in the previous section, it would be necessary to completely remove the flow of city water which presently supplies the basin on a year-round basis. Since the present supply of city water is quite large relative to the natural input of water from precipitation, this action may have sudden drastic effects on ecosystem functions. Furthermore, the potential for interpretive programs that could teach the public about fish habitat and lake ecosystems will be lost. Therefore, we recommend taking intermediary action. First, completely remove the supply of city water into the basin during the winter months. Second, set up an outflow point of city water at the top of Beaver Creek which can be turned on whenever the level of water falls below a critical level.

11.4.1. Scientific evidence

The amount of water being added to the hydrological regime through a city water pipeline was measured to be $0.184m^3/s$ during the winter months (Wu et al., 1999). Once converted into an equivalent daily rainfall depth, this volume of water represents a daily rainfall of 20mm. The summer input values were not measured but are known to be higher than winter input levels.. On an annual basis, the volume of city water added is over four times greater than the annual precipitation. This dramatically affects the lake basin. Instead of fluctuating between a full basin in the winter and a drawn down marsh in the summer, the lake remains as a relatively full basin year-round due to the city water input. The proposed recommendation attempts to maintain an annual fluctuation without allowing the lake to completely dry up, thus maintaining enough water to support an aquatic ecosystem. This is a valuable resource for educational purposes in an urban park. The constant addition of city water also artificially cools and aerates the lake and the

creek. Some cooling and aeration is important, but is unnecessary on a year-round basis. Furthermore, adding water to the basin year-round is a complete waste of chemically treated city water.

11.4.2. Logistics

Meeting this recommendation would require the implementation of a new system which inputs water directly into Beaver Creek at the junction with the lake. Furthermore, additional monitoring would be necessary so that the timing of the input water would coincide with the critical level in the creek which is required to maintain a small fish population. In order to determine this minimum level, further research is required. A final logistical problem that would need to be dealt with is educating the public about the natural flow regime. This would prevent regular park users from being shocked at the different patterns of water flow and lower lake levels.

11.4.3. Associated values

Decreasing the city water supply allows some natural successional and natural processes to occur (i.e. lake level fluctuations and creek dry up in summer). It allows for fish to exist in the system which enhances the interpretive value of the area. It recognizes present human impacts while ensuring that succession due to human impact does not occur at an alarming rate. Lastly, it does not create a huge disturbance to the area.

The current volume of water entering the basin is unnecessary. Decreasing the city water supply would decrease human influence on the basin while still allowing an open body of water and fish habitat to remain.

11.5. Replacement of the weir

The weir at the outflow of Beaver Lake needs to be replaced as it is old, incapable of passing storm event discharges, and impassable to fish.

11.5.1. Scientific evidence

The outflow culverts at the weir are too small and are incapable of passing large rain fall events. This has caused frequent flooding of the trail area and has introduced large quantities of sediment into Beaver Creek. The main weir is estimated to be able to pass $0.6m^3/s$ while the secondary weir is likely able to pass $0.13m^3/s$ when the stopping boards are in place (Wu *et al* 1999). This total discharge ($0.73\ m^3/s$) is far smaller than the 100 yr. flood ($3.3\ m^3/s$, Wu *et al* 1999) for which the weir structure should be built. In addition, the logs which hold the weir in place are becoming old[11] and could stand to be replaced. Lastly, an inspection of the culverts in the weir found their slopes to be 18 and 8 percent, for the main and secondary culvert, respectively. These slopes are much too steep for fish to pass. It is generally accepted that culverts up to a few percentage points are at the limit for fish passage.

11.5.2. Logistics

In replacing the weir plans like those described by Wu *et al* (1999) would likely be reasonable to follow. One of the major problems in replacing the weir is finding the funds to do it effectively. The weir structure is best replaced/ modified by an open channel structure flowing in the location of the secondary culvert. This may not be cheap or simple to build. This structure will not be straight forward as the overall gradient within which the structure must fit is steep, and the structure needs to prevent erosion of the banks of the creek, while being passable to fish. A step-pool structure might work well. The trail itself will also have to be modified, likely by putting in bridges across the channel. When replacing the structure it is likely best to set the new outflow level equal with the level at the bottom of the contemporary weir as this is the level the lake has adjusted to since the lake was originally raised.

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[11] The issue of just how old and how much the water level was raised is unknown, one possible way of determining this is constructing a dendrochronological (tree ring) record for the park and comparing the tree rings of the logs making up this weir with this record.

11.5.3. Values

This recommendation satisfies educational and interpretive values as it will increase the fish habitat and make the weir structure appear more natural. In addition to this a new weir which is passable for fish would enable natural migration between the creek and the lake to occur. The construction of a new weir would also help to remove past human impacts and prevent new ones by reconstructing lake outflow conditions.

The replacement of the weir is inevitable and should be done in a manner that most mimics the natural processes and makes it possible for fish to move from Beaver Creek to Beaver Lake.

12. Conclusions

When considering the actual implementation of our recommendations, we are struck by the difficult decisions the people of the BLEEP community group are faced with. A general approach to the management of the basin must be committed to. There is obviously a fundamental difference between allowing the lake to fill in and trying to maintain the lake as an open water body by dredging it. This decision will have very important impacts on the future management of the watershed. We think that by allowing the lake to fill in and setting up an interpretation program surrounding the successional processes seen in the basin, BLEEP could lead the way in implementing a more holistic approach to the management of urban parks and watersheds by recognizing the role that people play in natural ecosystems.

13. Acknowledgments

We would like to thank the many people who contributed to the success of this project. In particular, many thanks to Dr. Kathryn Harrison and Dr. George Spiegelman for their continued input and support throughout the year. We also extend great gratitude towards Dr. Mike Church (UBC Geography Dept.) for his valuable input and use of lab facilities, and to Dr. Les Lavkulich and Carol Dyck (UBC Soil Science Dept.) for constructive input and use of the soil chemistry lab for metals, nitrogen and carbon analyses. Our thanks also to Dr. Ken Hall (UBC Civil Engineering Dept.) and Dr. Burbee (UBC Botany Dept.) for equipment and sampling advice. Thanks to Dr. Black and Elyn Humphreys (UBC Soil Science Dept.) for assistance with the hydrology model. Many thanks as well to Mike MacIntosh and the members of the Beaver Lake Environmental Enhancement Project for their interest and input into the project. In addition, we would like to acknowledge the following people for their assistance with various aspects of the project:

Margaret North (UBC Geography Dept.)

Dr. Steyn (UBC Geography Dept.)

Brian Menounos (UBC Geography Dept.)

Shona Ellis (UBC Botany Dept.)

Jason Garratt

14. List of References

Aase, J.K. and S.B. Idso, 1978, A comparison of two formula types for calculating longwave radiation from the atmosphere, Water Resource Research, Vol. 14. pp. 623-625.

Anderson, M. and T. Burt, 1980, Interpretation of Recession flow, Journal of Hydrology, vol. 46, 89-101.

Arya. 1988. Introduction to Micrometeorology. Academic Press.

Ashmore, P.E. 1991. How do gravel-bed rivers braid? Canadian Journal of Earth Sciences. 28:326-41.

Ballard, Tim. 1997. Lecture in Soil Science 200, UBC.

Ballard, Tim. Personal Communication, 1999. Department of Soil Science, UBC.

Barnes, B., 1939. The structure of discharge-recession curves. Transactions of the American Geophysics Union, 20: 721-725

Beaver Lake Environmental Enhancement Project (BLEEP). 1996. Statement of Vision and Goals. Not published.

Beese, W. J. 1989. Stanley Park Regeneration Program: Folio I. Forest Management Plan. MacMillan Bloedel Ltd. Prepared for Vancouver Board of Parks and Recreation.

Beese, W. J. 1989b. Stanley Park Regeneration Program: Folio II. Support Reports. MacMillan
Bloedel Ltd. Prepared for Vancouver Board of Parks and Recreation.

Black, T.A. 1979, Evapotranspiration From Douglas Fir Stands Exposed to Soil Water Deficits, Water Resources Research, Vol. 15(1):164-170.

Boss, Mike. Personal Communications, phone interview, GVRD water district, February 19th, 1999.

Brunner, R. D. and T. W. Clark. 1997. A Practice-based Approach to Ecosystem Management. Conservation Biology. 11(1):48-58.

Callicott, J. B. and K. Mumford. 1997. Ecological Sustainability as a Conservation Concept. Conservation Biology. 11(1):32-40.

Church, Mike. Personal Communication. 1999. Department of Geography, University of British Columbia.

Church, Mike. Personal Communication B. 1999. Geography 205 laboratory. Department of Geography, University of British Columbia.

Coastal River Environmental Services. 1995. Comparative Environmental Assessment of Lions Gate Crossing Options Related to Stanley Park and First Narrows: Fisheries and Aquatic Resources. Prepared for Ministry of Transportation and Highways. Not Published.

Coulson, J., B. McDonald, and T. Worcester. 1998. Characterization of the Beaver Lake Bog Areas, Stanley Park, Vancouver. Capilano College Environmental Sciences Program. Not Published.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prestice-Hall Inc. Inglewood Cliffs, New Jersey.

Frissell, Christopher A., and David Bayles. 1996. Ecosystem Management and the Conservation of Aquatic Biodiversity and Ecological Integrity. Water Resources Bulletin. 32(2):229-240.

Geological Survey of Canada. 1979. Surface Geology: Vancouver. Map number 1486a, scale of 1:50 000.

Giles, D.G., T.A. Black, and D.L. Spittlehouse. 1985. Determination of growing season soil water deficits on a forested slope using water balance analysis, Canadian Journal of Forest Research, Vol. 15(1): 107-113.

Greater Vancouver Regional District (GVRD). 1974. Greater Vancouver. Map number 4b, scale 1:15 500□.

Grumbine, E. R. 1994. What is Ecosystem Management? Conservation Biology. 8(1):27-38.

Grumbine, E. R. 1997. Reflections on "What is Ecosystem Management?" Conservation Biology. 11(1)41-47.

Hatfield Consultants Limited. 1984. Beaver Lake-Creek Enhancement Study. Prepared for Vancouver Board of Parks and Recreation and Salmonid Enhancement Program: Department of Fisheries and Oceans. Not Published.

Hatfield Consultants Limited, 1985. A Technical and Economic Feasibility Study of The Beaver Lake/Creek Enhancement Project, Prepared for Vancouver Parks and Recreation Board and Salmonid Enhancement Program: Fisheries and Oceans. Not Published.

Heathcoate, Isobel W. Integrated Watershed Management: Principles and Practice. 1998. John Wiley & Sons, Inc. Toronto.

Hicken, E.J., and G.C. Nanson, 1984, Lateral migration rates of river bends. Journal of Hydraulic Engineering 110, 1557-67.

Knighton, D., 1998 Fluvial Forms and Processes: A New Perspective. Arnold, Great Britain.

Lashek J., T. Schmidt, and T. Scoffield. 1998. A study of disposal options & sediment quality for proposed dredgeate in Beaver Lake. Capilano College Environmental Sciences Program. Not Published.

Lavkulich, Dr. L. Soil Chemistry Laboratory Methods. Department of Soil Science, UBC.

Matthews, Rolf. 1999. Personal Communication. Professor, Simon Fraser University.

Mackenzie, S. H. 1996. Integrated Resource Planning and Management: The Ecosystem Approach in the Great Lakes Basin. Island Press: Washington, DC, USA.

McCallum, D.W., and K.J. Hall. 1998. Limitations of Sediment Quality Surveys: A Case Study of an Urban Watershed in British Columbia, Canada. Water Science Technology. 38(11):201-208.

McMartin, P. Date unknown. Rescuing Beaver Lake from chokehold means dredging the lilies. Vancouver Sun.

Mitsch, W.J. and J.G. Gosselink. Wetlands. 1986. VanNostrand Reinhold Company Inc. Agincourt, Ontario.

Munawar, M. and G. Dave. Development and Progress in Sediment Quality Assessment: Rationale, Challenges, Techniques & Strategies. 1996. SPB Academic Publishing. Amsterdam, The Netherlands.

N.D.. Lea Consultants Ltd. (1998). Drainage and Utility Relocation: Highway 9, Lions gate Project. Prepared for the BC Transportation Financing Authority. Map number: R1-377-H355 - not published

Nakamura, F. and F. Swanson, 1993, Effects of Coarse Woody Debris on Morphology and Sediment storage of a Mountain Stream System in Western Oregon, Earth Surface Processes and Landforms, Vol 18, 43-61.

Nuszdorfer, F. C., K. L. Kassay, and A. M. Scagel. 1985. Biogeoclimatic units of the Vancouver Forest Region. BC Ministry of Forest and Lands. Research Branch map, scale of 1:500 000.

Oke, Tim. Personal Communication. 1999. Department of Geography, University of British Columbia.

Post, D.A. and A.J. Jakeman, 1996, Relationships between catchment attributes and hydrological response characteristics in small Australian mountain ash catchments. Hydrological Processes, Vol 10, pp. 877-892

Pott, Ute. Assessment of Atmospheric Heavy Metals By Moss Monitoring with *Isothecium Stoloniferum* Brid. in the Fraser Valley, B.C., Canada. Master's Thesis, Biology, UBC, 1995.

Priestley, C. H. B. and R.J. Taylor, 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, Vol 100: 81-92.

Quin Brian. 1999. Personnel Communication. Stanley Park Horticultural crew Foreman.

Reasoner,M.A. and R.E. Healy, Identification and significance of tephras encountered in a core from Mary Lake, Yoho National Park, British Columbia, Canadian Journal of Earth Sciences, Volume 23, pp. 1991-1999

Robertson and Belchuys. Comparative Environmental Assessment of lions Gate Crossing Options Related to Stanley Park and First Narrows: Wildlife Resources. Prepared for Ministry of Transportation and Highways. Not Published.

Schaefer, V. and A. Chen. 1988. The Natural History of Stanley Park. Discovery Press: Vancouver.

Smakhtin, V.Y., K. Sami and D.A. Huges, 1998, Evaluating the performance of a deterministic daily rainfall- runoff model in a low-flow context, Hydrological Processes, Vol 12. pp. 797-811

Smoley, C.K. 1992. Methods for the Determination of Metals in Environmental Samples. Environmental Monitoring Systems Laboratory Office of Research and Development. U.S. Environmental Protection Agency: Cincinnati, Ohio, USA.

Spittlehouse, D.L. and T.A. Black, 1981, A growing seasonal water balance model applied to Douglas Fir stands, Water Resource Research, Vol 17(6). pp. 1651-1656.
Stanley, Jr., T. R. 1995. Ecosystem Management and the Arrogance of Humanism. Conservation Biology. 9(2):255-262.

Stanley Park Task Force. 1992. Final Report. Vancouver Board of Parks and Recreation.

Steele, M. 1985. The Stanley Park Explorer. Whitecap Books: North Vancouver, BC.

Steele, M. 1988. The First Hundred Years: An Illustrated Celebration. The Vancouver Board of Parks and Recreation: Vancouver.

Stevens, J.C. (date unknown), Hydrographic data book: Eighth Edition, Leopold and Stevens, Inc, Portland Oregon.

Stewart, J.M. 1997. Beaver Lake Bathymetric survey. J.M. Stewart Surveys Limited. Prepared for Beaver Lake Environmental Enhancement Project. Not Published.

Stull. R., 1995, Meteorology Today For Scientists and Engineers, West Publishing Company, St. Paul, Minneapolis.

Talisman Land Resource Consultants. 1995a. Comparative Environmental Assessment of lions Gate Crossing Options Related to Stanley Park and First Narrows: Soil and Drainage. Prepared for Ministry of Transportation and Highways. Not Published.

Talisman Land Resource Consultants. 1995b. Comparative Environmental Assessment of lions Gate Crossing Options Related to Stanley Park and First Narrows: Vegetation. Prepared for Ministry of Transportation and Highways. Not Published.

Tanner, C.B., and J.T. Ritchie, 1974, Evapotranspiration: Empiricisms and modeling, paper presented at Annual Meeting, American Society of Agronomy, Chicago, Ill. Nov. 1974.

Viswanadham, Y., V.P. Silva Filho and R.G.B. Andre, 1991, The Priestly-Taylor parameter $\propto$ for the Amazon Forest, Forest Ecology and Management, Vol. 38: 211-225.

Wetzel. Limnology. 1983. WB Saunders Co. Toronto.

Wu, B., and C., Starzyk., 1999, Civil 306,Assignment #3 Culvert Design/ Evaluation Project for the Beaver Lake weir.- un published - in appendix

Zecharias, Y. and W. Brutsaert, 1988, Recession Characteristics of Groundwater Outflow and Base Flow from Mountainous Watersheds, Water Resources Research, Vol. 24(10), 1651-1658.

15. Appendices

15.1. *Appendix I -Culvert flow design*

Prepared by: Ben Wu,,Cindy Starzyk - Civil 306
Assignment #3 Culvert Design/ Evaluation Project April 7, 1999
The relavent information to the weir is only given below

The maximum design velocity for the culvert will be limited by the burst speed of the adult Cutthroat. The lower limit of its burst speed is 1.9 m/s.

Beaver Lake is a small shallow water-body. It is fed by Prospect Creek, a southeast flowing creek from the highest elevation in the park. A four-inch pipe from the GVRD city water supply supplements the Creek headwaters with flow. In the summer when precipitation is low, this outflow controls the low flow condition. The pressure upstream of the pipe is 40 psi, which creates a discharge of 0.184m^3/s from the pipe into Prospect Creek. See appendix 3 for calculations.

Rainfall also supplies Beaver Lake with water. The watershed feeding Beaver Lake is an 84-hectare area, as seen in Figure 2.

The duration time required for storm data was found to be 30 minutes. This is the average time it takes a drop of rain to travel from the upper end of the catchment to the lake. The mean annual flood flow is estimated to be 1m^3/s, and the 1 in 10 year flood is 2m^3/s. These values were calculated from a 30 minute intensity rainfall determined from 1984 monthly precipitation and creek discharge data as measured by Hatfield Consultants Limited (Hatfield, 1985) and using an assumed runoff coefficient of 0.3 (typical value in forest cover).

The 30-minute rainfall intensity (as measured by The Vancouver Harbor weather station, Environment Canada) with a 100-year return period is 47.5mm per hour which would yield a flow of 3.325 m^3/s.

Current Culvert Geometry at Beaver Lake

A weir dams Beaver Creek and forms Beaver Lake. The weir is compromised of a series of three circular, concrete culverts. One 61 centimeter (inside diameter) pipe (culvert 1) that passes through the center of the weir and a series of two 44 centimeter (inside diameter) pipes (culvert 2 and 3) that is adjacent to the weir. Current culvert gradients are 18%, 6%, and 8.4% for culverts 1, 2 and 3 respectively. There is very little roughness within the pipe and flow is most likely supercritical. See Appendix 1 for the locations of each pipe.

The inlet for culvert 1 is a trapezoidal concrete weir structure. The water flows over the structure, drops 15 cm and then flows into the concrete pipe. It is equipped with a trash screen with a 10 cm bar spacing. See Appendix 2, Photograph 1.

A gate blocks the outlet of Culvert 2, sometimes a second board is in place to block water off at a higher level. The cross section of the culvert outlet is detailed in Figure 5-9. The inlet has no trash rack.

Figure 3. End View of Culvert 2

At the time of the site visit the outlet of culvert 3 was 15 cm above the level of the pool and a jet of water was shooting out from the pipe. See Photograph 3. This jet was hitting the opposite bank of the culvert and severely eroding and undercutting the stream bank.

The current capability of the culverts is as follows (Appendix 3)

	Culvert 1	Culvert2	Culvert 3
Area	0.292 m^2	0.152 m^2	0.152 m^2
Flow Capability	0.28m^3/s	0.61m^3/s	0.71m^3/s

Fish passage in not possible with the current culvert design. The culverts are much too steep and the flow is supercritical. The velocity and Q calculations do not meet Department of Fisheries and Oceans guidelines. The culvert is reported to overflow onto the trail on average every two years. Gravel derived from the trail is evident in the creek bed.

Design Requirements

Low flow	$0.184m^3/s$
High flow: 3 x bankfull area	$3.47m^2$
100 year flood return period	$3.325m^3/s$
Velocity in culvert at 1.5 bank full	1.9 m/s

The bankfull area of Beaver Creek downstream of the culverts was found to be $1.156m^2$. This measurement was calculated using a water level 20cm higher than the water level at the time of the site visit.

A culvert must be able to pass 3 times the bankfull area of water. This is equivalent to $3.47m^2$. The combined area of culverts 1 and 2 are $0.440m^2$, which is far below the required amount. As well, the 100 year flood flow is $3.325m^3/s$

The velocity of the water in the culvert at 1.5 times bankfull conditions should not exceed 1.9m/s and overall should have an average velocity no greater than 1m/s. Water traveling through the culvert at 1.5 times the bankfull flow would have a velocity of 3.94 m/s, failing again to meet criteria. See Appendix 3 for all above calculations.

Culvert Loading

The pressures due to soil loading on the culverts range from near zero (from an 8 cm cover of gravel) to 33.06 kPa at the outlet of culvert 1.

The wheel loading due to a 3000kg pick-up truck at the maximum depth of 1.87 meters would be 102.43 kPa. The overall loading the culvert would experience is then be 135.5 kPa. At the minimum depth of 8cm, the wheel loading on the culvert would be 56,000 kPa. See appendix 4 for calculations.

Design Recommendations

Existing culvert 1 could be left in place but blocked off and used only for overflow protection measures. During construction of the new culvert structure, the water can be passed via this culvert so flow is still maintained. Timing of the construction should be checked to minimized fish disturbance.

Culverts 2 and 3 could be replaced by 2 log culverts and a series of step pools. A culvert 3 meters wide by 1.15 meters deep (area of $3.47m^2$) would pass a 100-year flood event (Appendix 5). Making the bottom into a small arched shape replicating the shape of the natural channel would cause the culvert to satisfy minimum flow requirements.

The current grade of 6% and 8.4% for culverts 2 and 3 could easily be converted to a step and pool structure that will be able to pass fish. Around ten drops of 10 to 15cm each over the 15 meter length would accommodate the flow. A concrete brim at the Beaver Lake inlet end of the structure could be used to keep a good constraint on the level of the lake. No trash rack would be necessary.

The design would be a suitable choice for Stanley Park. The boulder, gravel and log construction will improve the esthetics of the site and keep it a natural landscape. An outlet pool constructed of coarse-grained rocks will prevent erosion, which is a current problem. See Appendix 5 for illustrations of this design recommendation.

Conclusions

The present culvert system installed at Beaver Creek fails to meet present design requirements. As a result, fish are unable to pass and frequent flooding occurs. The culvert design fails the following requirements:

- Does not pass water equal to three times the bankfull area (high flow condition)
- The velocity flowing through the culvert at 1.5 bankfull flow is too great to pass fish.
- The slopes, especially the 8.4% grade is too steep. The flow inside is also laminar.
- The outfall pond into Beaver Creek has too great of a drop.

The area could be easily remedied with the following design:

- Installing a 3m by 1.15m log culvert with natural arched gravel bottom. Steps and pools will easily accommodate fish passage.
- Create a log-enclosed area between culvert 2 and 3 so water is prevented from flooding the surrounding forest. Also install a log protection wall along the opposite bank to the discharges of culvert 1 and 3 to prevent erosion.

I. Capability of Culverts

Broad-Crested Weir: $Q=2/3(2/3g)^{1/2}bY^{3/2}$

Chezy-Manning equation: $Q=(c/n)AR^{2/3}S^{1/2}$

Assuming c=1.0, n=0.014 (for an unfinished concrete pipe),

R = Hydrologic radius = A/perimeter

Culvert 1:

Flow capability of broad-crested weir at inlet:

Y = .32m, b = 0.9m, $Q = 0.28m^3/s$

Flow capability of pipe:

$A = 0.292m^2$, R = 0.152 m, S= 0.18, $Q = 2.52m^3/s$

Culvert 1 is inlet controlled, maximum flow is $0.28m^3/s$

Culvert 2:

$A = 0.152m^2$, R = 0.11m, S = 0.06, $Q = 0.61m^3/s$

Culvert 3:

$A = 0.152m^2$, R = 0.11m, S = 0.084, $Q = 0.72m^3/s$

Culverts 2 and 3 are limited by culvert 2, maximum flow is $0.61m^3/s$.

II. Minimum Flow

Minimum flow requirements determined from GVRD pipe discharging into Prospect Creek:

Pressure in pipe: 40psi, (257.8 kPa)

According to Bernoulli's Equation: $(V^2/ 2g)$ = (P/symbol 103 \f "Symbol" \s 12γ)

V = 22.7 m/s

Radius of pipe: 2 inches (0.0508 m)

Area of pipe: $0.0081m^2$

Flow out of pipe: $Q=AxV=0.184m^3/s$

Low flow design criteria is **$0.184m^3/s$**

II. Maximum Flow

Maximum flow requirements were determined from three times the bankfull calculation:

Graph paper was used to measure the area off of the cross section to get a bank full area of $1.156m^2$

As well, the rainfall intensity with a 100-year return period is $3.325m^3/s$. This must also be considered.

IV. Velocity Restrictions:

Velocity in the pipes at 1.5 bank full flow are used as the high flow conditions to satisfy fish passage:

Bankfull area = $1.156 m^2$

$1.5Q_{bf} = 1.734m^2$

Combined area of culverts 1 and 2 :

Culvert 1 Area = symbol 112 \f "Symbol" \s 12π $(0.305)^2$ = $0.288m^2$

Culvert 2 and 3 Area = symbol 112 \f "Symbol" \s 12π $(0.22)^2$ = $0.152m^2$

Combined area = $0.440m^2$

Velocity = Q_{bf}/A = 3.94m/s

*This calculation did not utilize the Mannings equation simulating an inlet control, since the velocity in the pipe is already exceeding the limit when the calculation is preformed for a full pipe.

Soil Loading on Existing Culverts

Density of gravel: 1800kg/m3

Greatest culvert depth: 1.87m (at the outlet of culvert 1)

Pressure at the deepest culvert point: P = symbol 114 \f "Symbol" \s 12ρgh

P = (1800kg/m3)(9.81m/s2)(1.87m) = 33.1 kPa

Traffic Wheel Load on Existing Culverts

Weight of a pick-up truck: 3000kg

Assume the weight is evenly distributed over the four tires symbol 92 \f "Symbol" \s 12}

weight on one tire = 750kg.

From page 162, Craig, Sixth edition Soil Mechanics, 1997:

symbol 115 \f "Symbol" \s $12\sigma_z = QI_p/z^2$

Q = 750 kg z = $1.87 m^2$ I = 0.478

symbol 115 \f "Symbol" \s $12\sigma_z$ = (750)(0.478)/ (3.5) = 102.43 kPa

Total pressure on culvert at 1.87 meter depth.

$P = P_{soil} + P_{wheel} = 135.53$ kPa

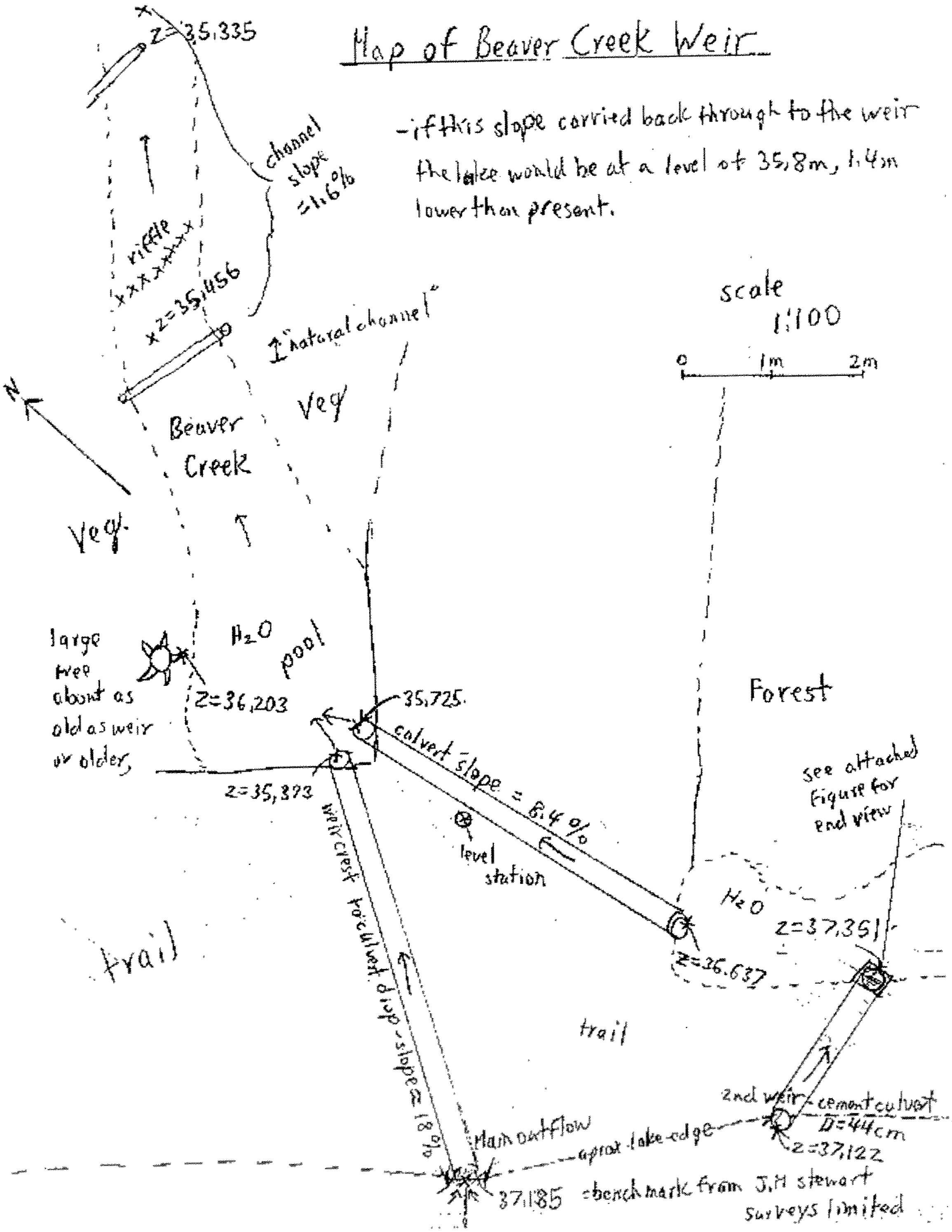
Wheel loading at the depth of 8cm (the minimum depth):

symbol 115 \f "Symbol" \s 12$\sigma_z = QI_p/z^2$

Q = 750 kg　　z = 0.08 m^2　　I = 0.478

= (750)(0.478)/ (0.0064) = 56,015 kPa

15.2. Appendix II plan view of weir



15.3. *Appendix III inorganic grain size analysis*

diameter (micro-meters)	AL4	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	Ah3	cumulative percent finer	mass in interval (%)
		0-156		275-323		323-355		372-475			0-57(1)	
250		100		100		100		100			100	
125.00		99.37	0.63	99.40	0.60	99.05	0.95	98.48	1.52		96.79	3.21
100.00		99.37	0.00	99.40	-0.00	99.05	0.00	98.48	0.00		95.82	0.97
80.00		99.37	0.00	99.40	0.00	99.05	0.00	98.48	0.00		94.66	1.16
60.00		98.67	0.70	99.10	0.30	99.05	0.00	98.48	0.00		90.79	3.87
50.00		98.57	0.10	98.51	0.60	99.05	0.00	98.48	0.00		86.72	4.07
40.00		98.08	0.50	97.41	1.09	98.16	0.89	98.48	0.00		80.14	6.58
30.00		96.79	1.29	96.72	0.70	97.47	0.69	98.48	0.00		69.98	10.16
25.00		95.89	0.89	96.12	0.60	96.57	0.89	97.49	0.98		63.01	6.97
20.00		93.71	2.19	93.64	2.49	95.19	1.39	97.20	0.30		54.59	8.42
15.00		85.46	8.25	84.79	8.85	91.42	3.76	97.00	0.20		44.91	9.68
10.00		45.71	39.75	50.79	34.00	76.27	15.15	94.93	2.07		33.29	11.61
8.00		21.26	24.44	33.10	17.69	64.98	11.29	93.36	1.58		28.46	4.84
6.00		13.51	7.75	25.05	8.05	52.30	12.68	89.62	3.74		22.65	5.81
5.00		11.82	1.69	22.46	2.58	45.17	7.13	87.84	1.77		19.26	3.39
4.00		10.14	1.69	19.98	2.49	37.24	7.92	70.41	17.43		15.68	3.58
3.00		8.55	1.59	17.00	2.98	28.63	8.62	16.84	53.57		12.49	3.19
2.00		6.76	1.79	12.33	4.67	19.71	8.91	4.23	12.61		9.49	3.00
1.50		5.27	1.49	8.95	3.38	14.36	5.35	4.23	0.00		7.36	2.13
1.00		2.98	2.29	3.98	4.97	7.53	6.83	3.84	0.39		4.94	2.42
median grain size		10.29		9.10		5.47		3.56			16.74	

diameter (micro-meters)	BL1	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer	mass in interval (%)	cumulative percent finer
		0-57		57-115		115-154		154-235		305-388		433-473		473-686
250		100		100		100		100		100		100		100
125.00		99.67	0.33	99.40	0.60	99.40	0.60	98.08	1.92	98.52	1.48	95.91	4.09	98.51
100.00		97.97	1.69	99.40	0.00	99.40	0.00	98.08	0.00	98.52	0.00	95.91	-0.00	98.51
80.00		96.68	1.30	98.50	0.89	98.70	0.70	97.98	0.10	98.52	0.00	95.14	0.77	98.51
60.00		92.69	3.99	96.12	2.39	96.22	2.48	97.49	0.49	98.52	0.00	93.71	1.44	98.51
50.00		88.11	4.58	93.04	3.08	93.14	3.08	97.00	0.49	98.52	0.00	92.94	0.77	98.51
40.00		80.23	7.87	86.28	6.76	86.38	6.76	96.41	0.59	98.23	0.30	91.88	1.06	96.64
30.00		68.37	11.86	74.85	11.43	74.95	11.43	95.72	0.69	96.95	1.28	89.10	2.78	94.28
25.00		60.90	7.48	68.68	6.16	68.78	6.16	94.74	0.98	96.16	0.79	86.90	2.21	92.51
20.00		52.13	8.77	61.53	7.16	61.53	7.26	93.76	0.98	95.76	0.39	84.31	2.59	88.86
15.00		40.46	11.66	48.11	13.42	48.21	13.32	91.70	2.06	94.78	0.99	78.36	5.95	65.81
10.00		27.61	12.86	23.46	24.65	23.46	24.75	86.01	5.69	80.99	13.79	55.15	23.21	11.23
8.00		23.12	4.49	17.30	6.16	17.30	6.16	82.48	3.53	44.63	36.35	30.69	24.46	8.08
6.00		17.64	5.48	14.21	3.08	14.21	3.08	75.32	7.16	6.60	38.03	14.96	15.73	7.68
5.00		14.75	2.89	12.92	1.29	12.92	1.29	61.10	14.22	3.65	2.96	12.28	2.69	7.39
4.00		12.06	2.69	11.73	1.19	11.73	1.19	24.72	36.39	3.35	0.30	10.17	2.11	7.09
3.00		9.67	2.39	9.74	1.99	9.74	1.99	2.75	21.97	3.25	0.10	8.54	1.63	7.09
2.00		6.48	3.19	7.06	2.68	7.06	2.68	2.06	0.69	3.25	0.00	6.62	1.92	7.39
1.50		4.39	2.09	5.47	1.59	5.37	1.69	1.77	0.29	3.05	0.20	5.08	1.53	7.39
1.00		2.19	2.19	2.78	2.68	2.68	2.68	1.57	0.20	2.27	0.79	1.92	3.17	7.19
median grain size		18.92		17.61		15.39		4.59		8.17		9.35		13.62

15.4. *Appendix IV - metals and organic*

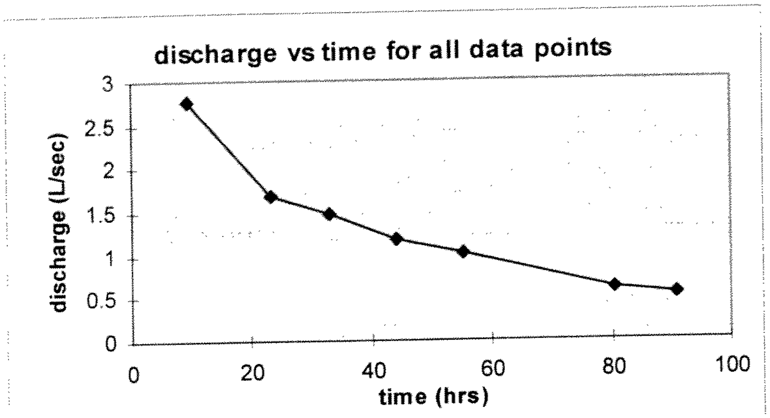
Sample	Depth (mm)	Al (ppm)	Ca (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (ppm)	Mg (ppm)	Mn (ppm)	Pb (ppm)	Si (ppm)	Zn (ppm)
AL4												
0-156	78.00	14470.84	4412.67	3.166	12.921	209.201	10555.71	2556.731	129.012	119.721	1091.8	439.024
156-275	216.00	14762.72	4535.82	3.518	13.302	218.944	10607.9	2602.191	128.286	121.068	1111.808	503.535
275-324	300.00	13392.88	4350.503	2.267	11.452	136.4	8565.585	2388.861	104.024	102.206	1950.569	338.322
324-355	340.00	14498.37	3314.979	1.094	11.006	37.618	8853.314	2437.622	105.42	64.018	2338.956	179.126
355-372	364.00	7394.963	4181.764	0.312	6.428	16.238	3488.011	827.375	56.361	17.886	796.39	89.713
372-410	391.00	5611.495	4415.038	0.156	4.237	14.884	2648.801	581.309	44.297	-3.855	298.548	261.505
410-434	422.00	5702.439	8857.904	0.351	2.781	10.284	4315.937	913.936	61.179	-8.176	356.218	35.16
434-475	455.00	5864.43	9378.923	1.055	5.916	27.063	4545.838	1241.914	68.081	-11.567	241.271	21.25
Al4 core plug												
BL1												
0-115	58.00	14546.81	4052.102	2.971	12.8095	156.698	12111.43	2454.872	129.3945	86.62	860.141	292.9105
115-154	135.00	10735.65	4603.907	1.954	10.258	95.805	9638.928	1711.794	112.991	62.253	437.034	180.613
154-188	171.00	7481.797	5490.823	0.664	6.637	30.852	5579.689	927.969	97.16	8.455	157.708	208.831
188-213	201.00	5869.519	5571.936	0.273	4.014	19.756	3765.867	577.655	79.896	-8.408	270.302	69.096
213-227	220.00	6999.151	6896.388	0.078	3.948	16.238	3492.242	680.761	76.646	-10.685	271.086	249.256
227-262	245.00	9994.389	5856.719	0.234	4.394	10.554	2407.616	625.544	48.943	-16.074	670.066	32.19
262-305	284.00	9939.211	4703.03	0.359	7.153	10.173	1985.71	575.5249	36.422	-22.294	656.285	44.142
305-330	318.00	12080.05	9036.116	0.508	3.856	17.591	3904.09	943.683	49.153	-23.135	406.826	84.809
330-365	348.00	9197.351	6217.288	0.586	4.014	8.93	2459.802	702.225	34.069	-15.888	491.173	19.091
365-388	377.00	12710.27	9552.397	0.469	4.604	10.825	3833.568	1060.8	46.133	-12.45	164.77	54.841
388-433	411.00	10476.38	7701.598	0.195	3.883	14.614	3023.977	906.464	33.228	-18.49	189.093	9.549
433-473	453.00	9282.62	5886.323	0.312	3.017	8.93	2287.729	582.305	30.933	-8.826	344.056	18.99
473-514	494.00	7820.459	10880.4	0.234	2.531	4.33	2303.244	1218.333	58.598	-9.988	42.369	13.238
514-571	543.00	5896.79	10503.85	0.351	2.991	13.802	4008.462	1257.317	53.914	-10.499	141.624	19.917
571-608	590.00	5120.759	9964.476	0.508	3.974	12.178	3863.187	1292.46	53.321	-13.937	79.639	32.681
608-651	630.00	3068.241	5285.968	0.43	4.775	12.449	2451.339	902.25	33.782	-12.729	401.333	37.522
651-686	669.00	4122.586	8490.231	0.078	4.42	15.155	3411.847	1183.895	50.779	-10.313	205.178	62.131
Hiller cores	dried segment depths (mm)											
Bh3	120.0	180.0										
Bh3	320.0	440.0										
AH3	0.0	57 (1)										
Ah4	0.0	35 (1)										
Ah7	311.0	363 (2)										
	414.0	501.0										

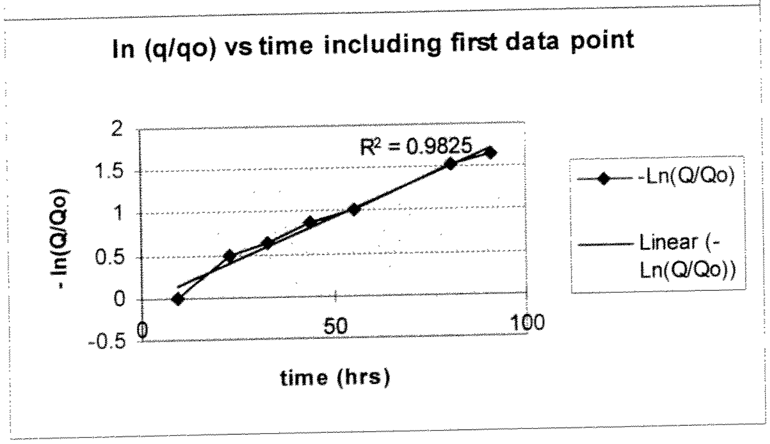
Sample	Depth (mm)	K (ppm)	Na (ppm)	organic %	bulk density Kg/m^3	inorganic density (kg/m^3)	organic density (kg/m^3)	%N	carbon (%)	carbon/ nitrogen
AL4										
0-156	78.00	735	329	46.08251	43.82834	23.63114	20.1972	1.5974	23.797	14.89733
156-275	216.00	742	399	44.78382	26.48282	14.6228	11.86002		23.0774	
275-324	300.00	3360	1848	46.67719	190.1598	101.3985	88.76124	1.3933	24.127	16.56312
324-355	340.00	550	427	41.14328	194.7288	114.611	80.11783	1.085	18.79	17.31797
355-372	364.00	366	525	62.087	212.6259	80.61285	132.013	1.8072	32.669	18.07714
372-410	391.00	484	749	84.47658	199.0569	30.90043	168.1564	2.2402	45.075	20.12097
410-434	422.00	148	490	76.18475	243.8599	58.07582	185.784	1.5071	40.4798	26.8594
434-475	455.00	70	420	90.5467	165.1898	15.61588	149.5739	1.7428	48.439	27.79378
Al4 core plug				59.6925						
BL1				ave.	159.4915					
0-115	58.00	479	304.5	33.05	240.29	160.807	79.485	0.8835	16.23	18.37
115-154	135.00	400	210	40.4881	166.0498	98.81939	67.23041	1.4116*	19.34	13.70
154-188	171.00	154	301	68.72317	126.5779	39.58957	86.98837	1.4116*	29.59	20.96
188-213	201.00	88	280	72.4827	106.6086	29.33581	77.27279		38.43	27.22
213-227	220.00	94	329	84.24793	88.82952	13.99249	74.83703	1.6125	44.83	27.80
227-262	245.00	72	315	75.22495	111.0335	27.50862	83.52492	1.8653	39.95	21.42
262-305	284.00	100	266	66.16771	144.5338	48.89909	95.63472	1.5564*	34.38	22.09
305-330	318.00	77	350	82.323	142.2432	25.14432	117.0988	1.5564*	43.88	28.19
330-365	348.00	62	350	70.78198	129.6015	37.867	91.73451	1.6493	38.79	23.52
365-388	377.00	66	308	89.23855	166.596	17.92815	148.6678	1.1521	47.71	41.41
388-433	411.00	72	315	81.29659	160.1537	29.95421	130.1995	1.1289	45.41	40.22
433-473	453.00	79	238	62.79573	255.9361	95.21918	160.717	0.8295	33.06	39.85
473-514	494.00	82	287	86.09949	133.7809	18.59622	115.1847	1.0979	48.59	44.26
514-571	543.00	40	364	91.49913	116.6931	9.919929	106.7732		48.97	44.60
571-608	590.00	60	357	94.24859	101.8959	5.860457	96.03547	1.1563	51.68	44.69
608-651	630.00	69	371	63.47379	134.6226	49.17254	85.45009	0.7337	33.44	45.57
651-686	669.00	56	462	90.81863	84.73223	7.779582	76.95264	1.1817	49.35	41.76
Hiller cores	dried segment depths (mm)			ave.	141.7752					
Bh3	120.0			6.649964						
Bh3	320.0			5.363553						
AH3	0.0			3.884902						
Ah4	0.0			3.010453						
Ah7	311.0			2.488517						
	414.0			1.238637						

*= combined sample

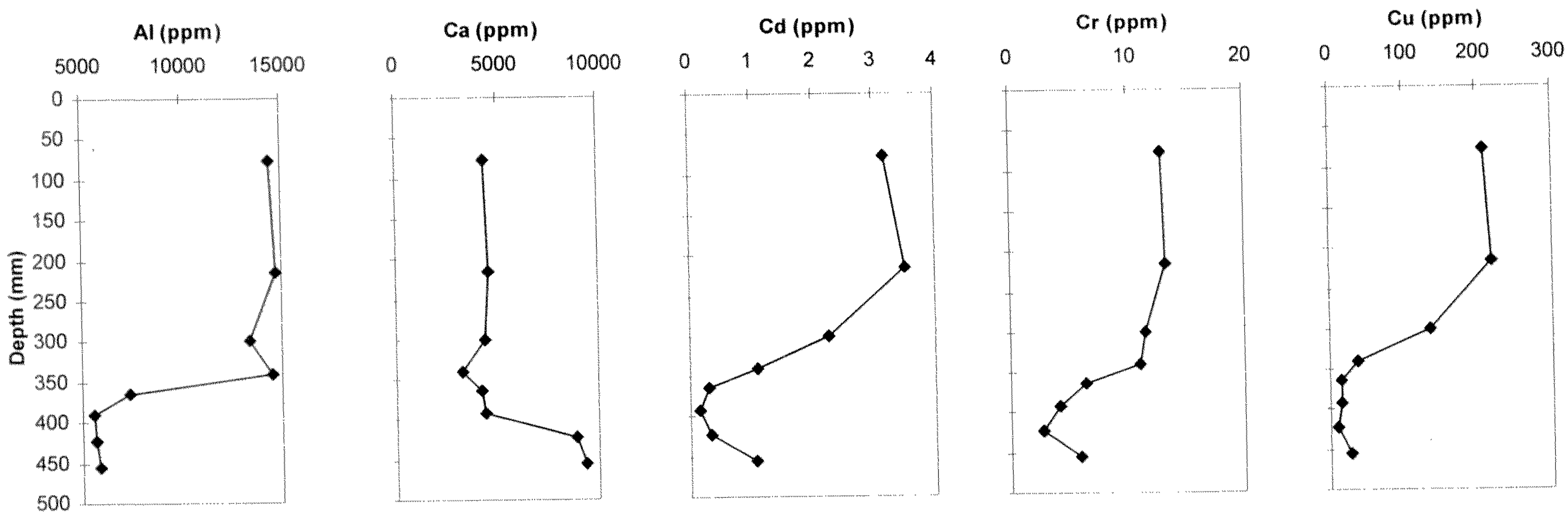
15.5. Appendix V - recession data

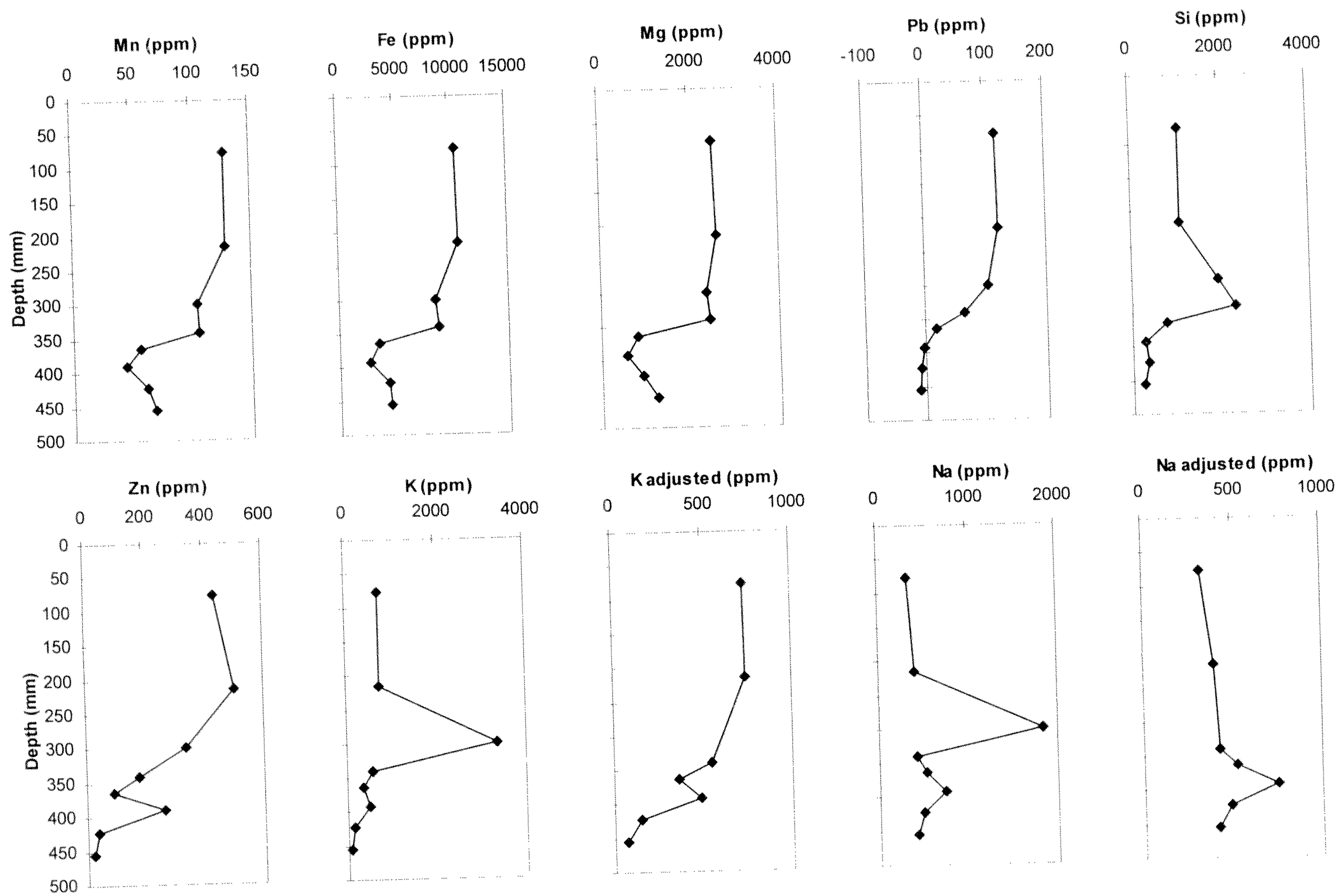
volume (liters)	mean run time (sec)	time 0= 12pm Dec. 17th (hrs)	discharge (L/s)	Q/Qo	without 1st sample ln(Q/Qo)		k(total)= (Hr^{-1})
9.575	3.460	9.330	2.767	1.000	-0.000	not used to calculate k	0.0194
9.575	5.685	23.083	1.684	0.609	0.497		k(less 1st=
9.575	6.500	33.000	1.473	0.532	0.631		0.0177
9.575	8.151	44.167	1.175	0.424	0.857		r(total) =
9.575	9.400	55.330	1.019	0.368	0.999		0.9912
9.575	15.996	80.500	0.599	0.216	1.531		r(less 1st)=
9.575	18.143	91.000	0.528	0.191	1.657		0.9978

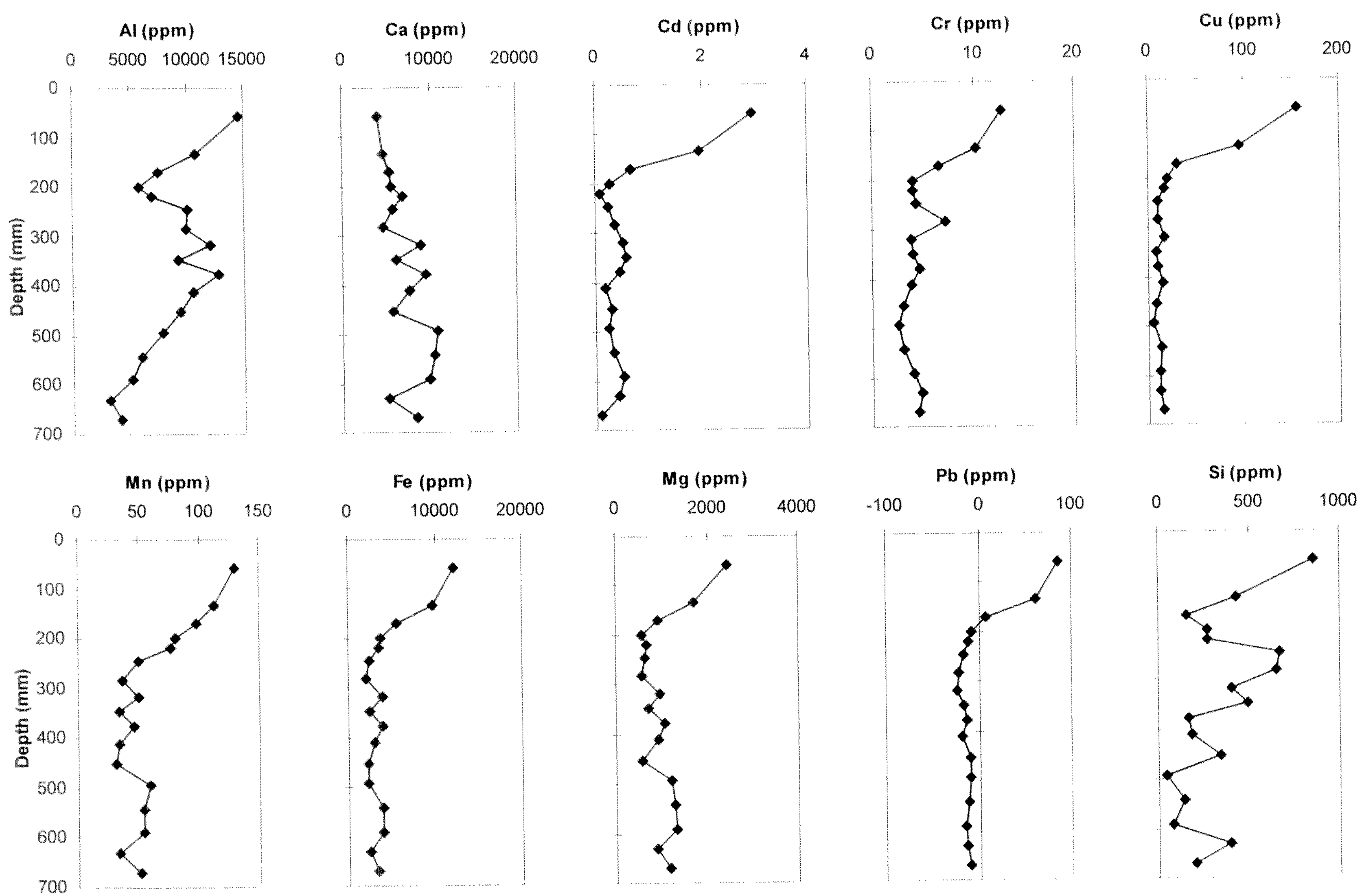




15.6. *Appendix VI metals, not normalized by carbon*




Mn (ppm)
Fe (ppm)
Mg (ppm)
Pb (ppm)
Si (ppm)
Zn (ppm)
K (ppm)
K adjusted (ppm)
Na (ppm)
Na adjusted (ppm)
Depth (mm)
Depth (mm)



Al (ppm)
Ca (ppm)
Cd (ppm)
Cr (ppm)
Cu (ppm)
Mn (ppm)
Fe (ppm)
Mg (ppm)
Pb (ppm)
Si (ppm)
Depth (mm)
Depth (mm)

15.7. Appendix VII -Moist and ground up core descriptions

Depth (mm)	Munsell Colour	Description AL4 moist
0-275	10YR 2/2	top - organic matter, fine vegetation bottom - OM, coarser veg.
275-355	5YR 2.5/1	OM, finer veg.
355-410	7.5YR 2/0	as above
410-475	5YR 2.5/1	OM, few pieces coarse veg., mostly fine

Depth (mm)	Corrected Depth (mm)	Munsell Colour	Description AL4 dry
0-96	0-156	10YR 5/2	light grey/brown; some fine veg.; some white specks on outside
96-169	156-275	10YR 5/2	more veg.; filamentous roots; large chunk of root; black inside (rubbery smell)
169-243	275-323	10YR 6/2	slightly paler; filamentous OM; bits of charcoal
243-291	323-355	10YR 4/2	more brown ; fewer filaments; large pieces of charcoal
291-311	355-372	10YR 4/2	woody root at top; more filaments
311-355	372-410	10YR 2/2	dark, almost black; white flecks at bottom
355-370	410-434	10YR 2/1	very dark; white flecks; fine and compact
370-395	434-475	5YR 3/2	suddenly slighter lighter with reddish tinge; long strip of charcoal; no more white flecks

AL4 dry

Corrected Depth (mm)	Munsell Colour Moist	Munsell Colour Dry	Chroma Moist	Chroma Dry
0-156	10YR 2/2	10YR 5/2	2	2
156-275	10YR 2/2	10YR 5/2	2	2
275-324	5YR 2.5/1	10YR 6/2	1	2
324-355	5YR 2.5/1	10YR 4/2	1	2
355-372	7.5YR 2/0	10YR 4/2	0	2
372-410	7.5YR 2/0	10YR 2/2	0	2
410-434	5YR 2.5/1	10YR 2/1	1	1
434-475	5YR 2.5/1	5YR 3/2	1	2

AL4 dry and ground

Corrected Depth (mm)	Ground Description
0-156	greyish; very fine silts and sands
156-275	same
275-324	flecks of OM (detritus)
324-355	similar particle size; fewer stems; fine roots
355-372	same but few roots
372-410	lots of detritus
410-434	darker; woody material; lots of detritus
434-475	well-decomposed OM

BL1- moist

Depth (mm)	Munsell Colour	Description
0-115	10YR 3/2	light in colour, fine veg.
115-227	10YR 3/2	light in colour, coarse veg. (roots, chunks of OM)
227-262	10YR 2/1	dark colour, intermediate veg.
262-305	10YR 2/2	light colour, fine veg.
305-330	10YR 2/1	dark colour, fine veg.
330-365	10YR 2/2	lighter, fine veg., roots present
365-388	10YR 2/1	dark colour, fine veg.
388-433	10YR 2/2	lighter, fine veg.
433-473	10YR 2/2	lighter, fine veg. Compact, clay-like
473-500	5YR 2.5/2	dark colour with shades of brown, fine veg.
500-514	5YR 2.5/1	darker, almost black, fine veg.
514-571	10YR 2/2	lighter than previous five sections, chunks of coarse veg.
571-608	10YR 2/2	colour as above, less veg.
608-651	10YR 2/2	intermediate veg., sand particles at bottom of segment
651-686	5YR 2.5/1	almost black, more veg., few roots

BL1- dry

Depth (mm)	Corrected Depth (mm)	Munsell Colour	Description
0-90	0-115	10YR 5/2	grey/brown, fine veg.
90-118	115-154	10YR 5/2	more veg.
118-143	154-189	10YR 4/2	darker brown
143-161	189-214	10YR 4/2	lighter brown
161-171	214-235	10YR 3/2	darker brown
171-193	235-262	5YR 2.5/1	almost black
193-223	262-305	10YR 4/2	more brown shades
223-240	305-330	10YR 3/2	slightly darker; some black attached
240-260	330-365	10YR 3/1	more grey; darker
260-277* i)260-274 ii)274-277	365-388 i)365-384 ii)384-388	i)10YR 2/1 ii)5YR 3/3	i)almost black ii)very thin reddish layer
277-307	388-343	5YR 2.5/2	dark with some grey further down
307-342	433-473	10YR 5/1	very grey
342-372	473-514	10YR 2/2	crumbly, reddish-brown
372-407	514-571	5YR 2.5/2	more reddish
407-432	571-608	5YR 2/1	black, fine sediment, little veg.
432-458	608-651	5YR 2/1	black with distinct layer of white specks (pebbles)
458-476	651-686	5YR 2.5/1	black with white specks

BL1 dry

Corrected Depth (mm)	Munsell Colour Moist	Munsell Colour Dry	Chroma Moist	Chroma Dry
0-115	10YR 3/2	10YR 5/2	2	2
115-154	10YR 3/2	10YR 5/2	2	2
154-189	10YR 3/2	10YR 4/2	2	2
189-214	10YR 3/2	10YR 4/2	2	2
214-235	10YR 3/2	10YR 3/2	2	2
235-262	10YR 2/1	5YR 2.5/1	1	1
262-305	10YR 2/2	10YR 4/2	2	2
305-330	10YR 2/1	10YR 3/2	1	2
330-365	10YR 2/2	10YR 3/1	2	1
365-388	10YR 2/1	i)10YR 2/1 ii)5YR 3/3	1	1 3
388-443	10YR 2/2	5YR 2.5/2	2	2
433-473	10YR 2/2	10YR 5/1	2	1
473-514	5YR 2.5/2	10YR 2/2	2	2
514-571	5YR 2.5/1	5YR 2.5/2	1	2
571-608	10YR 2/2	5YR 2/1	2	1
608-651	10YR 2/2	5YR 2/1	2	1
651-686	10YR 2/2	5YR 2.5/1	2	1

BL1 ground

Corrected Depth (mm)	Ground Description
0-115	fine-grained; sands and silts; decomposed OM
115-154	same; coarser OM
154-189	same
189-214	same; no undecomposed OM
214-235	darker, with roots and OM
235-262	hardened charcoal
262-305	same
305-330	finer, more silty, no OM
330-365	more aggregated
365-388	fine sands and silts
388-343	sands and silts, aggregated into secondary particles
433-473	sands and silts, aggregates ~2mm; OM
473-514	stronger aggregation; large chunks of OM
514-571	similar but less aggregation; less OM
571-608	similar
608-651	flecks of white, sand-size particles
651-686	similar but fewer white particles