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WET DETENTION POND DESIGN FOR HIGHWAY RUNOFF POLLUTANT CONTROL

FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

David Yonge, Akram Hossain, Mike Barber, Shulin Chen
Washington State University
Pullman, Washington

And

Dixie Griffin
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DISCLAIMER

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SUMMARY OF FINDINGS

The overall objective of this research was to develop a fundamentally sound method for designing wet detention ponds to treat highway stormwater runoff. This was achieved by collecting highway runoff and wet pond discharge data during storm events at two selected sites in Washington (Vancouver and Spokane) with differing climates and rainfall patterns. The design approach culminated in the development of a decision support system (DSS) program that allows the user to predict the performance of an existing wet pond or size a wet pond to achieve desired effluent water quality.

A 1:12 scale model of the Spokane pond was constructed and tracer tests were performed to define pond hydraulic characteristics under a range of inlet configurations. These data were used to develop default values for the DSS.

Numerous storm event, water column and sediment samples were collected from the Washington wet ponds over a two-year period. These samples were analyzed for a range of constituents that included metals, nutrients, suspended solids, COD, PAH, and toxicity. In addition, pond water column and sediment samples were collected and analyzed for the same constituents. The data was compiled in a database and analyzed to determine constituent retention effectiveness of the ponds. TSS and total metal (Cu, Pb, and Zn) concentrations were found to be significantly reduced during each storm event in the Vancouver and Spokane wet ponds. Soluble metal concentrations, however, showed no general trend of concentration reduction from the pond influent to effluent. Effluent concentrations of all metals were found to be below the surface water quality standards for the state of Washington.

Nitrate was the only nutrient found to have a seasonal pattern in the Spokane pond discharge concentrations. Removal of nitrate was positive in the warmer months during algae growing seasons, and was negative during the colder months during algae senescence. In contrast, TKN and ammonia had positive removal efficiencies throughout the year, based on storm event, event mean concentration (EMC) values. Average phosphorus concentration reduction for all storm events was poor with essentially no removal of ortho-phosphorus and approximately 30% removal of total phosphorous.

Rainfall patterns in Spokane and Vancouver had an effect on the presence or absence of a first flush of pollutants into the pond. For the coastal northwest, the more typical first flush behavior was minimal to nonexistent because of the small, frequent rain pattern characteristics of marine influenced climates of the northwest. Mediterranean climates have the majority of precipitation during the winter months, and for the inland northwest, this precipitation comes in the form of snow. All of the winter storm events investigated, except for one, had the pattern of a first flush for total metals but no first flush was observed for soluble metals. For the three remaining seasons, the presence or absence of a first flush coexisted for total and soluble metals. When a first flush occurred, the metals exhibiting the greatest first flush phenomenon was in the order Pb>Zn>Cu>Cd.

PAH compounds were detected in stormwater runoff and in water column samples in both Vancouver and Spokane. The most prevalent were pyrene, fluoranthene, phenanthrene, and benzo(a)anthracene which are all reported to be emitted by automobiles. Although pond water column samples occasionally tested positive for PAH, all pond effluent samples tested were below the MDL for PAH.

Mildly toxic results were observed for 7 of 13 storm event samples tested. Only one effluent sample (Vancouver pond) exhibited a toxicity and this sample was also the only one to exhibit acute toxicity. No determination was made regarding the cause of toxicity however, and this would be a potential area of future research.

Scale model tracer testing indicated that wet ponds behave primarily as a CSTR with significant dead volume. This, and other factors, directed the numerical modeling toward a relatively straightforward 1-D predictive code. The code, imbedded within a decision support system, yields reasonably accurate predictions of TSS and metal removal and affords the user a means of generating wet pond outflow hydrographs.

The results of this research show that wet ponds are effective at removing many of the commonly found pollutants in highway runoff. Simple wet detention ponds, however, may not be sufficient for treating dissolved highway runoff constituents, the fraction that the USEPA has recommended to set and measure compliance with water quality standards.

1 CHAPTER 1
INTRODUCTION AND RESEARCH APPROACH

Historically, most efforts to control water pollution focused on reducing direct point source discharges into surface water bodies (1). Despite intensive efforts to improve water quality via end-of-the-pipe treatment methods, many water bodies still did not comply with water quality standards for recreational use. This realization prompted an investigation of other sources, including nonpoint source (NPS) pollution. A 1986 U.S. Environmental Protection Agency (USEPA) report indicated that for approximately two-thirds of impaired water bodies, NPS pollution was the primary cause for the depreciated conditions (2). In 1989, the USEPA again identified NPS as the major continuing cause of water quality deterioration in receiving bodies (3).

Highway stormwater runoff's contribution to NPS pollution is a well known phenomenon (4-13). Highway runoff constituents that are frequently cited as being of concern include heavy metals, sediment, nutrients, and hydrocarbons (4,4,14,15). A popular and cost effective approach for improving the quality of highway runoff entering surface water bodies is wet detention ponds (16-19). Wet ponds have been described as detention systems comprised of "a permanent water pool, a temporary storage area above the permanent pool, and a littoral zone planted with native aquatic vegetation" (20). The USEPA states that in general, a higher level of nutrient removal and better overall storm water quality control can be achieved in wet detention ponds than can be achieved in other retention systems such as dry ponds, infiltration trenches, or sand filters (21).

To properly design wet ponds for highway runoff, the dual functionality that most runoff control devices provide must be understood. The two often-competing considerations are hydraulic and environmental (22). The primary hydraulic consideration is to size the basin to mitigate downstream flooding. Satisfaction of hydraulic constraints must be established in terms of local drainage criteria. Environmental considerations are focused on the quality of the discharged water and pollutant removal efficiency of the ponds. The conflict that can exist between hydraulic and environmental design is created by the fact that from a hydraulic viewpoint, the optimum condition is to store the water just long enough to meet the drainage criteria and then release it so that most of the storage volume is then available for the next storm event. For environmental mitigation, however, the ideal condition may be to store all of the water for an extended period of time so that physical, chemical, and/or biological processes can take place to improve quality of the effluent.

Designing wet ponds to effectively intercept and treat highway runoff is still in its infancy. Case studies and design manuals are available to the design engineer, but current designs are generally applicable only regionally and contain more "art" of designing than engineers have come to expect (16-19,23-26). Despite its nascent state, wet pond design has been charged with the responsibility of addressing some very complex environmental problems. Due to the inherent complexities of NPS pollution, in many instances designers have not been able to define the technical requirements of stormwater management that will necessarily meet the regulators' treatment goals. For example, it is easier to specify the treatment goal of reducing total metals concentration by 80%, than it is to specify the exact technical measures required to meet that reduction in a cost effective manner. To address that deficiency, the USEPA funded the development of a plan for urban wet-weather flow management and pollution control research needs and anticipated research directions for the next five years (14). The research plan was divided into five major areas, each discussing a specific wet weather flow question. Three of the areas highlighted for research were:

1. Characterization and problem assessment of urban stormwater effects on receiving waters,
2. Impacts and control of toxic pollutants, including heavy metals and organic chemicals, and
3. Wet weather flow control technologies, specifically low-cost natural systems.

To overcome the disparity between technical requirements and treatment goals and to develop appropriate stormwater management and mitigation technologies, a broad understanding of the current knowledge base pertaining to highway water quantity and quality issues is required. While runoff volume from highways can be estimated relatively accurately using hydrologic models such as SWMM, similar accuracy in characterizing the contaminant concentrations in the runoff is not currently available (27). Highway runoff pollutant concentrations have been shown to be dependent upon traffic volume, time between storms, rainfall intensity and duration, seasonality, and surrounding land uses (5,28). These time-variant factors that control runoff quality result in a design process that can be problematic unless a better understanding is gained regarding the significance of these factors on overall contaminant detention in a wet pond.

1.1 Constituents of Concern in Highway Runoff

A list of typical highway stormwater constituents and their concentrations is presented in Table 1. As indicated in the table, highway runoff exhibits a wide range of both constituent type and concentration. Reported concentrations for some constituents, such as Cu, vary by more than two orders of magnitude. While this sort of variation is the exception rather than the rule, the range of concentrations and loads reported can easily vary by a factor of 10 or more. Similar variability has been reported in nearly every study devoted to quantifying stormwater pollutant concentrations in highway runoff (6,29-31). This is a result of the broad range of system specific conditions that affect runoff quality. The challenge becomes, therefore, to determine which constituents have a high potential to exhibit negative environmental impacts at anticipated concentrations and to determine how best to design a wet pond to minimize potential impacts.

Table 1. Constituents of highway runoff - ranges of average values (4).

Constituent	Concentration (mg/L unless noted)	Load (kg/ha/year)	Load (kg/ha/event)
SOLIDS			
Total	437 - 1147		58.2
Dissolved	356	148	
Suspended	45 - 798	314 - 11,862	84 - 107.6
Volatile, dissolved	131		
Volatile, suspended	4.3 - 79	45 - 961	0.89 - 28.4
Volatile, total	57 - 242	179 - 2518	10.5
METALS (totals)			
Zn	0.056 - 0.929	0.22 - 10.40	0.004 - 0.025
Cd	ND - 0.04	0.0072 - 0.037	0.002
As	0.058		
Ni	0.053	0.07	
Cu	0.022 - 7.033	0.030 - 4.67	0.0063
Fe	2.429 - 10.3	4.37 - 28.81	0.56
Pb	0.073 - 1.78	0.08 - 21.2	0.008 - 0.22
Cr	ND - 0.04	0.012 - 0.010	0.0031
Mg	1.062		
Hg (x 10^{-3})	3.22	0.007	0.0007
NUTRIENTS			
Ammonia, as N	0.07 - 0.22	1.03 - 4.60	
Nitrite, as N	0.013 - 0.25		
Nitrate, as N	0.306 - 1.4		
Nitrite + Nitrate	0.15 - 1.636	0.8 - 8.00	0.078
Organic, as N	0.965 - 2.3		
TKN	0.335 - 55.0	1.66 - 31.95	0.17
Nitrogen, as N	4.1	9.80	0.02 - 0.32
Phosphorous, as P	0.113 - 0.998	0.6 - 8.23	
MISCELLANEOUS			
Total coliforms number/100 Ml	570 - 6200		
Fecal coliforms number/100 mL	50 - 590		
Sodium		1.95	
Chloride		4.63 - 1344	
pH	7.1 - 7.2		
Total Organic Carbon	24 - 77	31.3 - 342.1	0.88 - 2.35
COD	14.7 - 272	128 - 3868	2.90 - 66.9
BOD 5	12.7 - 37	30.60 - 164	0.98
Polynuclear Aromatic Hydrocarbons (PAH)		0.005 - 0.018	
Oil and Grease	2.7 - 27	4.85 - 767	0.09 - 0.16
Specific Conductance (µmohs/cm @ 25°C)	337 - 500		
Turbidity (JTU)	84 - 127		

1.1.1 Sediment and Metals in Runoff.

The most frequently cited constituents of concern in highway runoff are sediment and toxic metals. Both are known to cause negative environmental impacts and since a significant fraction of metals are often associated with sediment as a metal-particulate complex, metals and sediment should be considered together when designing contaminant concentration reduction devices. For example, Greb and Bannerman investigated the influence of particle size on wet pond effectiveness (32). They determined that ponds needed to remove particles smaller than 2 µm in order to control toxic pollutants present in runoff.

Historically, metals were regulated on a total metal concentration basis. More recently, however, and the USEPA has recommended the use of dissolved metal concentration to set and measure compliance with water quality standards because the dissolved form more closely approximates the bioavailable fraction in the water column than does total recoverable metal (33). The fraction of dissolved metals in solution can be affected by system specific conditions that include the concentration and type of particle matter, pH, and solution chemistry (major anion and cation type and concentration). Evidence exists suggesting that, in general, the fraction of dissolved metals is inversely proportional to suspended solids (particulate matter) concentration. This is a result of the sorptive capacity of particulate matter for certain metal species. Consequently, at higher suspended solids concentrations, one could expect a larger fraction of metals to be bound to the particles (34). Unfortunately, there are data that both support and contradict this generalization. If the data is accepted at face value, its' contradictory nature could be a result of system conditions other than suspended solids concentration (e.g., pH and/or the physical and chemical characteristics of the particulate matter) or the fact that some data sets have low suspended solids concentrations relative to other data sets. In addition, those investigations that analyze and evaluate only very low or very high solids concentrations and not a range of concentrations, may show little correlation between dissolved and particulate bound metal concentrations.

For example, some researchers have found significant fractions of specific heavy metals in highway runoff in the dissolved phase (10,35). In a study of highway bridge runoff, Marsalek et al. (1997) found the dissolved fractions of Cd and Pb to be below the detection limit (10). However, the average soluble concentrations of Cu, Ni, and Zn were 0.047, 0.031, and 0.148 mg/L, respectively, or 35% to 45% of the total metal load in the runoff. Furthermore, they found poor correlations between metals and suspended solids, concluding that a significant dissolved metal load was present in the highway bridge runoff (10). Morrison *et al.* found Zn and Cd to be mainly present in the soluble phase of stormwater runoff, while Pb was found in the dissolved phase only 12% of the time above the limit of detection (36). Copper was fairly evenly distributed between the soluble and insoluble phases. In a study of particles and metals from an urban watershed, Characklis *et al.* (37) found dissolved Zn ranged from 44% to 83% of total Zn and dissolved Fe ranged from 6% to 43% of the total Fe. As a result, they suggested that for the case of Zn, presence in the dissolved phase might render simple detention basins a relatively ineffective form of treatment. Yousef *et al.* in investigating highway runoff in detention ponds found that Cd, Ni, and Cu were generally present in dissolved fractions that were about 50 to 75% of the total metal. Lead and Fe were approximately 5 to 20% in the dissolved phase, and Zn and Cd were 30 to 50% in the dissolved fraction (13).

1.1.2 TPH and PAH in Runoff

Concern has been raised regarding the accumulation of hydrophobic organic contaminants in our environment. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are known to bioaccumulate and some of the compounds within these groups are toxic and/or potential carcinogens to higher organisms including fish and humans (38,39). One significant source of PAHs is vehicular emissions with most being emitted in the form of phenanthrene, fluoranthene, and pyrene (40). A number of studies have been performed that quantify PAHs in highway and urban runoff, but few have been performed that evaluate the effectiveness of wet ponds to retain PAHs (41). Since PAHs have low solubility, it would be anticipated that they would exist primarily in the particulate-bound form in runoff. Two studies that evaluated roadside soils and soil in a swale showed that PAHs were retained within the first 5 cm and that concentrations decreased rapidly to below detection in deeper samples (42,43).

1.1.3 Metals in Wet Ponds.

Mesuere and Fish (1989) found dissolved Pb and Cd were very low in all urban stormwater runoff detention pond water samples and most samples were below detection limits (44). In contrast, they reported that dissolved Cu was greater than 1.0 μg/L in most samples, usually in the 3-10 μg/L range, and occasionally as high as 15 μg/L. Dissolved Cu showed little depth-specific differences, indicating that the ponds were generally well mixed, but it appeared to exhibit a seasonal cycle related to the climate of the maritime northwest. Dilute input from steady winter and spring rains induced low Cu levels in the water column from midwinter into the summer. They concluded that a significant increase in dissolved metals in the ponds occurred in the fall, possibly from a combination of high-metal runoff and the decay of accumulated algae.

Lee *et al.* (1997) investigated the geochemical mobility of soluble metals in a detention pond receiving highway runoff (9). At the sediment-water interface conditions can exist that lead to complex chemical and biochemical reactions affecting fluxes of dissolved trace metals between the sediment and the water. Metals bound to particles and organic matter were reported not to be fixed permanently and may have been recycled through geochemical and biological reactions in response to changes of physical and chemical conditions. In general, it was found that the concentrations of all the metals in the interstitial water showed a definite tendency of decreasing in the deeper sections of sediment cores, regardless of the sample location. Cadmium and Mn were considered the most mobile elements in the retention pond, with a reported relative mobility sequence of Mn>Cd>Zn>Pb>Fe (9).

In general for detention ponds receiving stormwater runoff, Zn and Cd are more often stated by researchers as being present in the dissolved phase, while Fe and Pb are more often reported being present in the particulate phase. Investigators have described Cu as varying from generally soluble to fairly evenly distributed between soluble and insoluble phases.

1.2 Contaminant Retention in Wet Ponds

Several studies have been performed regarding constituent retention in detention ponds. A pilot scale study of a detention pond in Jarnbrott, Sweden provided the following result: total suspended solids (TSS) removal of 14% to 82%, Zinc removal of 32% to 74%, and Lead removal of 10% to 82% (16). These data are typical in that they indicate a wide range of pollutant retention effectiveness for each constituent studied. This is due to the complex and interrelated phenomena that can affect retention in a wet pond. In the Pettersson study, the pollutant removal capacity was greatly influenced by the antecedent dry periods for each storm event. A study of pollutant removal by a stormwater detention pond in Greenville, N.C., showed median pond treatment efficiencies were 71% for TSS, 45% for particulate organic carbon and particulate nitrogen, 33% for particulate phosphorus, and 26-55% for metals (45). A combined probabilistic-deterministic simulation of a detention pond located in an mining area of Raleigh County, West Virginia, indicated that pond designs seldom meet the regulatory requirements for sediment concentration on a daily or monthly basis, even though they may comply with annual sediment yield requirements (46). Nevertheless, investigations have shown that suspended solids reduction can be significant in detention ponds (47).

In addition, wet ponds have the potential to reduce influent soluble pollutants, such as, Ammonia (NH_3), Nitrate (NO_3^-), and Phosphate (PO_4^{3-}) by biological uptake. The uptake and transformation mechanism will be dependent upon total pond biomass, reaction rates, and hydraulic retention time within the pond. The removal can be expedited by artificial growth of aquatic plants. Duckweed mixtures in stormwater ponds, for example, have been found to be effective for the removal of total Kjeldahl nitrogen (TKN), total phosphorus (TP), and NH_3 (48). Generally, however, reported nutrient removal effectiveness is less than for suspended solids and negative removals have been reported. For example, a study of several wet ponds yielded a range of PO_4^{3-} concentration reduction of 20%-57% and nitrate concentration reduction range of –17%-60%, while suspended solids reductions in the range of 39%-91% were reported (49).

As previously stated, numerous system specific conditions affect the contaminant retention effectiveness of wet ponds. If we consider only the wet pond itself, and take a reactor theory approach to assessing the probable controlling factors, we would consider pond hydraulics (flow phenomena and mixing) and its impact on sedimentation, metal partitioning onto particulate matter, and reaction rates as they pertain to biological nutrient uptake. The following subsections discuss the in-pond factors with regard to their affect on wet pond performance.

1.2.1 Flow Phenomena and Mixing

The degree of mixing plays a vital role in the overall performance of a detention pond. The principal mechanisms of mixing are diffusion and dispersion. Diffusion, a result of random molecular motion, will not have a significant impact on mixing in the water column of wet ponds. Dispersion, the scattering of particles by the combined effects of shear and transverse diffusion, accounts for the majority of mixing within most wet ponds. Quantifying the degree of mixing, or dispersion within a reactor (wet pond), is an essential first step toward developing a predictive tool that can be used to define performance.

Two idealized mixing models, continuously stirred tank reactor (CSTR) and plug flow tank reactor (PFTR), have been widely used in analyzing the mixing characteristics. These models describe the extremes in mixing; a CSTR assumes perfect and complete mixing and a PFTR assumes absolutely no longitudinal mixing (50). Unfortunately, wet ponds will exhibit neither complete mixing nor plug flow but will have some intermediate degree of mixing. Additionally, ponds will likely exhibit a certain degree of short-circuiting that renders a portion of the volume of the pond ineffective. This portion of the pond is often referred to as a dead zone. The degree of mixing and percent dead zone (effective volume) can be estimated through the performance of inert tracer experiments. These tracer tests result in effluent concentration-time data that can be analyzed to quantify mixing characteristics (50,51).

1.2.2 Sedimentation

It is generally accepted that the performance of a wet pond is primarily dependent on suspended solids removal since pollutants such as metals and PAH are often primarily associated with solids. Consequently, the concentration of many stormwater pollutants are regarded as being proportional to the concentration of total suspended solids (TSS) in stormwater, and the modeling of TSS removal may thus provide a reasonable estimate of overall pollution control performance of detention ponds (52). Consequently, therefore, to move beyond the prediction of TSS removal to other contaminants such as PAH and metals, the degree of partitioning of constituents must be defined.

1.2.3 Contaminant Partitioning

Contaminants can be present in two phases in aqueous solution; either dissolved or sorbed to the sediment (particulate matter). The equilibrium partition coefficient for dilute solutions represents the ratio of solid phase metal concentration (metal mass on the solid phase normalized to the dry mass of solids) to the liquid phase metal concentration. Factors that affect partitioning in a wet pond system include the concentration and type of both the sorbent (particulate matter) and contaminant. For example, the size of sediment has been shown to be inversely proportional to metal partition coefficients, with the smaller particles retaining the largest fraction of metals (53). Solution conditions such as pH and ionic strength also impact the degree of contaminant partitioning. Unfortunately, little data exists that either directly reports contaminant partition coefficients in stormwater

1.3 Adequacy of Existing Design Criteria

1.3.1 Necessity of Modeling

Development of design criteria for wet ponds can be complicated due to the non-ideal flow characteristics that would be typical in a wet pond setting. The flow phenomenon in these ponds is unsteady and is governed by pond configuration, inlet/outlet condition, rainfall-runoff characteristics, and many other factors. The hydraulic characteristics within wet ponds also vary over time as it fills with sediment or as aquatic vegetation grows and dies over the seasons. Under these complex, time-variant conditions, mathematical modeling can be an indispensable tool to assist in quantifying flow and contaminant transport as well as storage and treatment phenomena in wet ponds under a wide variety of conditions. One of the primary advantages of modeling is that it affords a means of defining factors that control dependent variables of interest in complex systems, wet pond TSS and total metal discharge concentration as a function of average flow, for example.

The approach to model development in such complex systems can take two tracks. First, one could attempt to completely describe pond flow characteristics through a complex 3-D model. These type models require detailed input parameters for each system being modeled if they are to accurately represent system hydraulics and ultimately, contaminant retention. If these parameters are unavailable, as would likely be the case for most wet ponds, then numerous assumptions have to be made to develop a set of input parameters. If all or most of the input parameters are assumed, any perceived advantage of using a more complex model is essentially negated.

The second approach would be to utilize a simple 1-D model and evaluate and calibrate the model with reliable data to see if it yields an acceptable level of predictive accuracy over a wide range of conditions. If the model yields acceptable results, there is no need to consider more complex numerical models. An obvious advantage of 1-D models is there relative ease of use; an important consideration if one of the goals is widespread use in the design environment.

1.4 Sedimentation and Maintenance

Pond maintenance can directly affect the overall success of the stormwater management program. The frequency of maintenance has a large impact on both upkeep costs and water quality, and it is the designer's responsibility to achieve an appropriate operating maintenance schedule. The designer should always strive to minimize the overall amount of maintenance at the pond and to make that amount as easy as practicable to perform (54). According to Yu, the most important routine maintenance functions are cutting grass and weeds, removing sediment, repairing any erosion, and cleaning out debris (18). In particular, deposited sediment, as well as floating plant growth, and vegetation growing in the sediment, needs to be periodically removed from the basin to ensure that the intended hydraulic function of the pond is not impeded.

Another study found that the flood control capacity of a dry detention basin receiving stormwater runoff had been significantly reduced because of sedimentation over its 18-years in existence (55). The initial design capacity of the basin decreased from a 13-year storm to a 4-year storm. A second study of a stormwater dry detention pond revealed that only 0.16% of the pond storage volume had been lost per year due to suspended solids retention (45). In determining that percentage, the author assumed that the sedimentation was evenly spread over the pond. Stanley (1996) suggested that trash accumulation and woody vegetation growth in the pond may reduce the storage volume much more rapidly than sedimentation (45).

1.5 Objective

The overall objective of this research was to develop a fundamentally sound method for designing wet detention ponds to treat highway stormwater runoff. This was achieved by collecting highway runoff and wet pond discharge data during storm events at two selected sites in Washington with differing climates and rainfall patterns.

Additional runoff data was collected at a third site in Louisiana but was not used in defining wet pond design criteria because the pond receiving the runoff was operated in a zero discharge mode during most of the year. The design approach culminated in the development of a decision support system (DSS) program that allows the user to predict the performance of an existing wet pond or size a wet pond to achieve desired effluent water quality. The overall objective was met by performing the following specific project tasks.

- Collect and analyze wet pond influent and effluent samples during storm events for.
- Collect and analyze pond water column samples for constituents including metals (total and soluble), nutrients, TSS, chlorophyll a, and PAH/TPH.
- Collect and analyze algae in the Spokane pond for metals during the summer months.
- Collect and analyze sediment, and sediment interstitial water for constituents including total and soluble metals.
- Continuously monitor rainfall, flow, pH and conductivity at each field site.
- Define pond hydraulic characteristics (hydraulic residence time, effective volume, dispersion and mixing) by performing inert dye trace studies on a 1:12 scale model of the Spokane wet pond.
- Determine the amount of sedimentation and the mass distribution of sediment by collecting field survey data over time.
- Develop a decision support system that incorporates design criteria developed from the field and laboratory data.

2 CHAPTER 2
EXPERIMENTAL METHODS

2.1 Experimental Sites

Two wet ponds in the state of Washington that received highway runoff were selected for contaminant retention evaluation. A third pond was selected that was located in Shreveport, Louisiana. Since this pond was operated as "zero discharge" for most of the year, it was not used for the development of wet pond design criteria. One Washington pond was located on the western coast of Washington in Vancouver, near Portland, OR; the second pond was located on the eastern side of Washington in Spokane, near the Idaho border. The Vancouver pond at Leverich Park was built in the summer of 1978 to receive highway runoff from approximately 3.2 km (2 mi) of north and southbound lanes of Interstate 5. The wet pond received runoff from approximately 5 ha (12 ac) of land. This runoff area was 95% I-5 and 5% 40th Street exchange, with an Average Daily Traffic (ADT) of 101,000. Vancouver, WA had an annual rainfall of 94 cm (37 in), with the wet season occurring during the winter and spring months. This pond had a permanent pool of water for approximately 10 months out of the year and a respective full-pool volume, surface area and average depth of 1140 m^3, 929 m^2, and 1.2 m. During extended dry periods in July and August, evaporation and infiltration exceeded inflow, causing the pond to dry out.

The Spokane pond at the interchange of Interstate 90 and State Highway 190 was built in the fall of 1993 to receive stormwater runoff from approximately 1.6 km (1 mi) of east and west bound lanes of Interstate 90 and their associated unpaved medians and shoulders. The wet pond drainage area consisted of approximately 10 ha (25 ac) of pavement and 6.4 ha (15.8 ac) of pervious land within the right-of-way limits with an ADT of 49,400. Spokane, WA had an average annual rainfall of 42 cm (16.5 in), with the wet season occurring during the winter and spring months. This pond had a permanent pool of water throughout the year as a result of intercepting groundwater springs during construction. The respective full-pool volume, surface area, and average depth of the pond were 1857 m^3, 2378 m^2, and 0.9 m.

2.2 Wet Pond Scale Model Development

Both wet ponds were surveyed using an electronic total survey station (Topcon, Model AT-G4) to generate contour maps using Surfer 6.01 (Figure 1 and Figure 2). The Spokane pond was selected for scale model development and the survey data used to establish the physical shape and dimensions. The inlet structure was a 0.9 m (3 ft.) diameter circular concrete pipe entering into the north side of the pond at a slope of 2.9%. A year round base flow of approximately 0.02 m^3/sec (0.8 ft^3/sec) flows into the pond. The outlet structure was a 0.6 x 1.2 m (2 x 4 ft.) flat rectangular grate located at the northeast corner of the pond. Surface water enters through the grate into a drop structure, and is then conveyed away from the pond via a 0.45 m (1.5 ft.) diameter corrugated metal pipe.

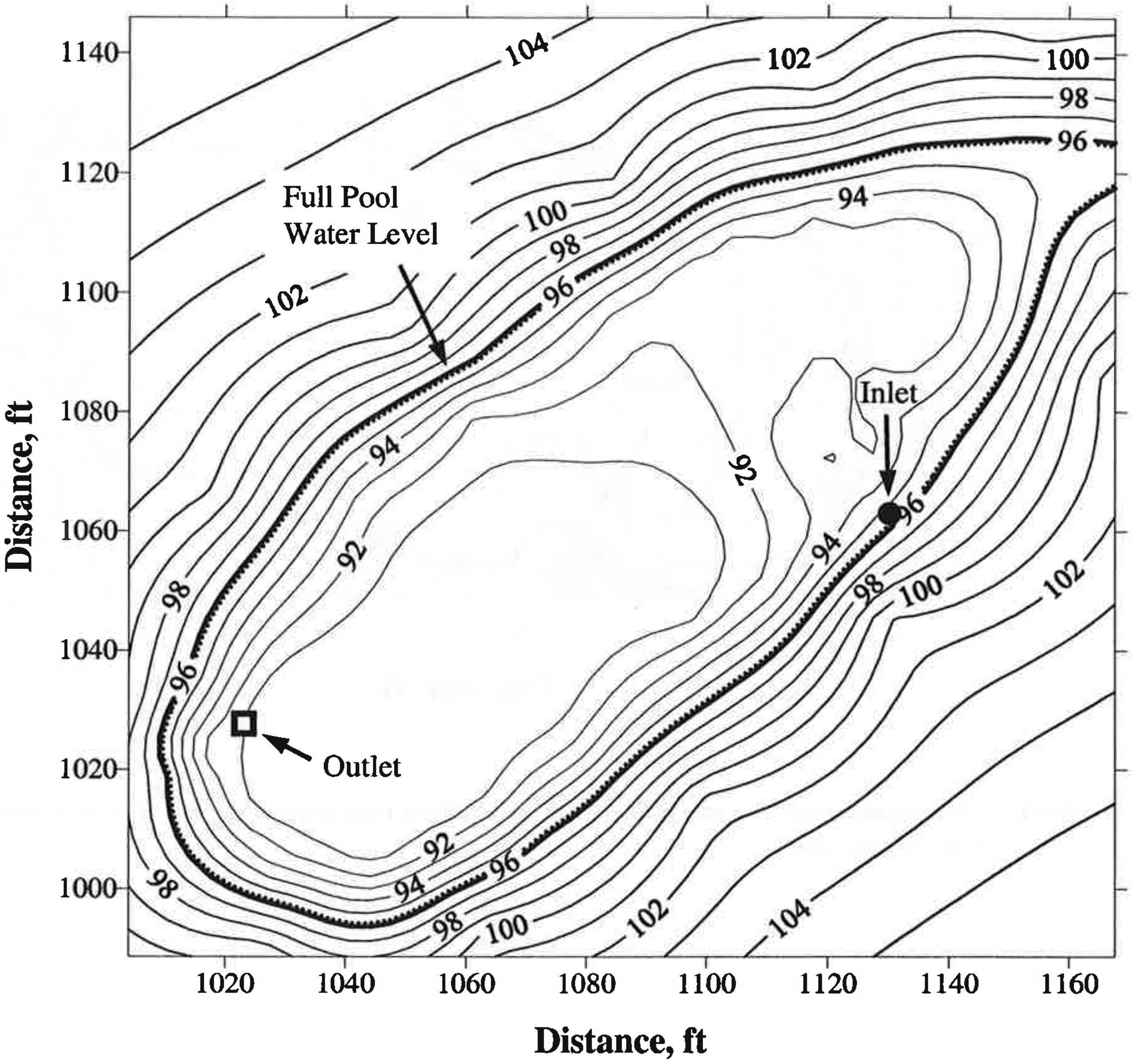


Figure 1. Contour map of the Vancouver, Washington wet pond showing the inlet and outlet locations.

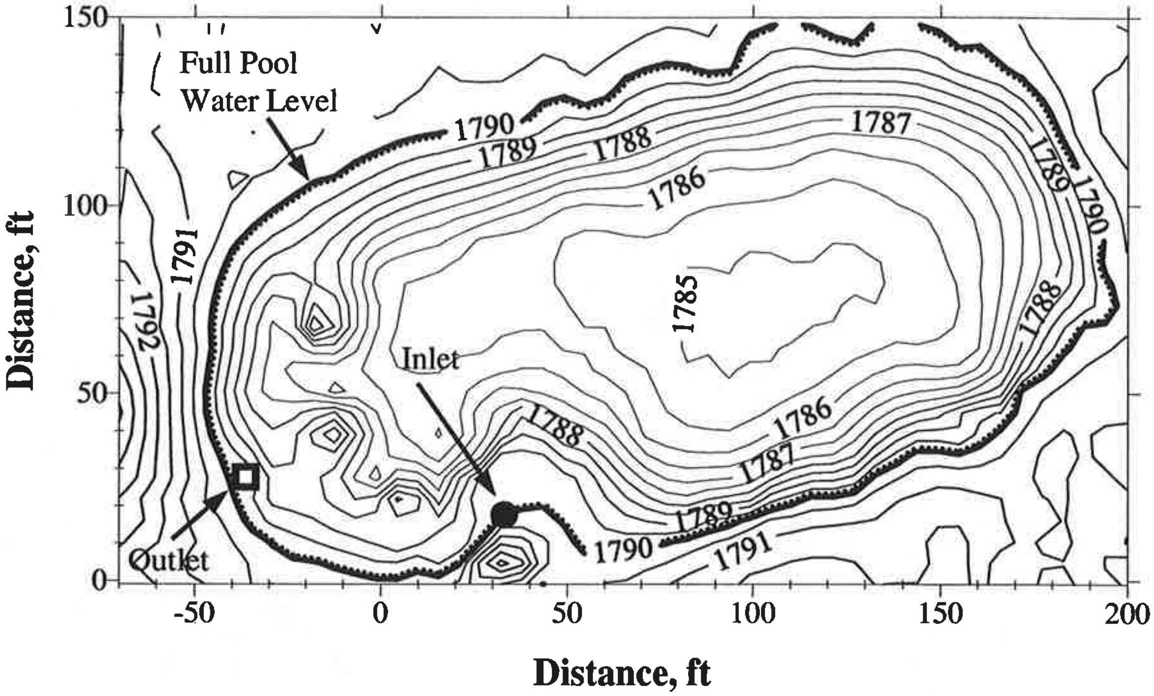


Figure 2. **Contour map of the Spokane, Washington wet pond showing the inlet and outlet locations.**

A number of factors influenced the selection of the model scale. The model had to be large enough to diminish the effects of the viscous forces and avoid excess influence from bottom friction and surface water tension, all of which could play a significant role in altering the dynamics and therefore adversely affect the reliability of the results from a smaller model. The model also had to be small enough to be economically feasible, relatively easy to construct, and fit within the confines of the space provided. A scale model ratio of 1:12 (model to prototype) was chosen as the best compromise to the above considerations.

Once the length scale was selected, all other scales are fixed and the Froude number was used to scale the model parameters. Scaling factors according to the Froude number are as follows: length scale = L, velocity scale = $L^{1/2}$, area scale = L^2, flow scale = $L^{5/2}$, time scale = $L^{1/2}$, volume scale = L^3. The data in Table 2 summarize the results of the scaling under Froude law relationships.

2.2.1 Model Construction

A 6.7 m (22 ft.) long by 3.8 m (12.5 ft.) wide by 0.3 m (1 ft.) deep box frame was constructed out of plywood strips to house the model. The frame was sized to allow for 7.6 cm. (3 inches) of excess on all sides of the model. A total of 15 cross sections were placed width-wise within the frame. The first and last cross sections were spaced 50.8 cm. (20 inches) from the frames' end cross sections. The remaining cross sections were placed 40.6 cm. (16 inches) apart on center. Each cross section member was cut to model the contours of the cross section of the pond that it represented prior to placement in the frame. To do this the cross sections were first drawn out on the surfer contour map and the distance between elevation changes measured and scaled to model size. Distances and elevation changes were then marked on the cross sections and cut to fit the contours. The result produced a scaled profile of the bottom contours of the pond.

2.2.2 Elevation Guidance and Leveling

To ensure that the frame was level, the elevations of the corners were measured using an electronic total station (Topcon, Model AT-G4) and then brought up to equal elevation using shims. Metal lathe was next placed across the cross sections and nailed in place to roughly represent the bottom of the pond. Numerous 4-inch screws were then driven approximately 2.5 cm into the cross sections marking each change in elevation. Each screw's elevation was measured using a digital level and crosschecked with the electronic total station to ensure proper representation of the pond bottom surface.
The placement of the inlet and outlet structures was then measured and determined. A hole was cut into the metal lathe in the corresponding location of the outlet structure and another in the side of the frame at the closest point. A 5.1 cm (2 inch) diameter PVC pipe was then temporarily inserted through the holes to represent the placement of the outlet structure.

Table 2. Parameters resulting from the scale modeling effort.

Parameter	Scale	Pond	Model
Length (m)	L	78.5	6.6
Width (m)	L	34.9	3.7
Inlet Diameter (m)	L	0.9	0.08
Outlet Dimension (m)	L	0.6X1.2	0.05X0.1
Flow (m^3/s)	$L^{(5/2)}$	0.1	$1.9x10^{-4}$
Volume (m^3)	L^3	1857	1.07

2.2.3 Concrete Placement and Finishing

The next step in the model construction was to place a lightweight, crack resistant, concrete base over the metal lathe to the elevation of the screws. A "Pool-base" expanded perlite mixture was used for the concrete. Perlite is a hydrous silicate mineral that expands greatly when heated and is often used for the purpose of insulation. "Pool-base" perlite is specially modified for use in the construction of pools and other applications requiring lightweight concrete. To ensure adequate strength, a 1:4 ratio, cement/perlite, recipe was selected yielding a compressive strength in the range of 21–35 kg/cm^2 (300-500 lb/in^2). Approximately 1.15 m^3 (40.5 ft.^{3}) of concrete was required to lay a 7.6 cm. (3 inch) base over the metal lathe. The concrete was trowelled into place and made level with the tops of the screws to represent the contours of the bottom of the pond. To provide a surface for the outlet grate, a flat 6.4 x 12.7 cm. (2.5 x 4 inch) plate with a 5.1 cm (2 inch) diameter hole was fitted over the outlet pipe and leveled

After curing, the concrete was sanded to a smooth finish and painted with Gacoflex Aromatic Urethane Coating U66, a rubber based epoxy. The pond was then filled and a water surface elevation established. For the inlet, a 1.8 m (6 ft.) long 7.6 cm. (3 inch) diameter PVC pipe was fitted at a 2.9% slope from the water surface. The pipe ran away from the pond at the determined inlet location. The temporary outlet pipe was removed. An open 5.1 x 10.2 cm. (2 x 4 inch) Plexiglas box representing the outlet grate was fitted onto the level platform at the outlet. The top of the box was measured to correspond with the water surface elevation. A 5.1 cm (2 inch) diameter PVC pipe was run from beneath the level platform to the drain.

2.3 Model Tracer Studies

Dye tracer experiments were conducted in a scale model of the Spokane wet pond. Two field tests were also conducted on Spokane wet pond in order to compare results. All tests consisted of a pulse input of FWT Red fluorescent dye, a specially formulated version of the dye Rhodamine WT (hereafter referred to as Rhodamine WT). Concentrations were recorded at known times at the outlets using a Turner Designs, Model 10-AU-005 Field Fluorometer. The fluorometer was calibrated to 200 parts per billion (ppb) with a linear range between approximately 10 ppb, and 400 ppb. All measurements exceeding the linear range were diluted to achieve an accurate reading. Analysis of results included C(t) Curves (time versus concentration), F(t) curves, (time versus fraction of mass remaining in pond), and the procedure presented by Rebhun and Argaman to describe hydraulic efficiency (51).

2.3.1 Analysis Procedure

The Rebhun and Argaman analysis quantifies the various flow regimes within a system utilizing a graphical method based upon earlier work by Wolf and Resnick (51,56). The Rebhun and Argaman equation allows one to quantify mixing in sedimentation basins.

$$F(t) = 1 - \exp^{-\left(\frac{1}{(1-p)(1-m)}\left[\frac{t}{\theta} - p(1-m)\right]\right)} \qquad (1)$$

where *F(t)* represents the fraction of the tracer mass remaining in the tank; *m* is the dead space fraction of the tank volume; *1-m* is the effective volume of the tank; *p* is the plug flow fraction of the effective volume; and *1-p* is the perfectly mixed fraction of the effective volume.

Wolf and Resnick determined that the F(t) function for a real system had the

form:

$$F(t) = 1 - e^{\frac{-a(t-\theta)}{T}} \tag{2}$$

where a and θ represent constants expressing the ratio between flow types within a system, t is time and T is hydraulic retention time. Rebhun and Argaman gave physical meaning to the constants a and θ in equation 1, with:

$$a = \frac{1}{(1-p)(1-m)} \tag{3}$$

and:

$$6 = p(1-m) \tag{4}$$

Rearranging Rebhun and Argaman's equation (Equation 1) and taking the natural logarithm of both sides produces:

$$\ln[1 - F(t)] = -\frac{t}{(1-p)(1-m)\theta} + \frac{p}{(1-p)} \tag{5}$$

in the form of Y = mx + b. In this form, the two unknowns (*p* and *m*) can be solved for. Plotting ln[1-*F(t)*] versus t/θ produces a plot with a straight line portion. ln[1-*F(t)*] has a value of zero until the breakthrough time (time of first arrival of tracer at the outlet. By setting ln[1-*F(t)*] equal to zero and using the breakthrough time divided by the theoretical hydraulic residence time, and the slope of the straight line portion of the plot, the variables *m* and *p* can be solved for.

Some subjectivity is inherent in the analysis procedure, primarily in the determination of slope and breakthrough time. The slope of the straight-line portion of the graph is dependent upon the choice of points use for it's determination. The procedure is fairly sensitive to change in slope. During the analysis of the experiments conducted for this research slopes were chosen in a consistent manner thought best to represent the largest portion of the straight line.

The breakthrough time was chosen as the point at which the slope intercepts the x axis. Trace amounts of dye are generally detected at the inlet prior to this time but the value of ln[1-F(t)] is still approximately zero. An example plot is shown below, () to give a clearer understanding of the determination of the values used for the analysis.

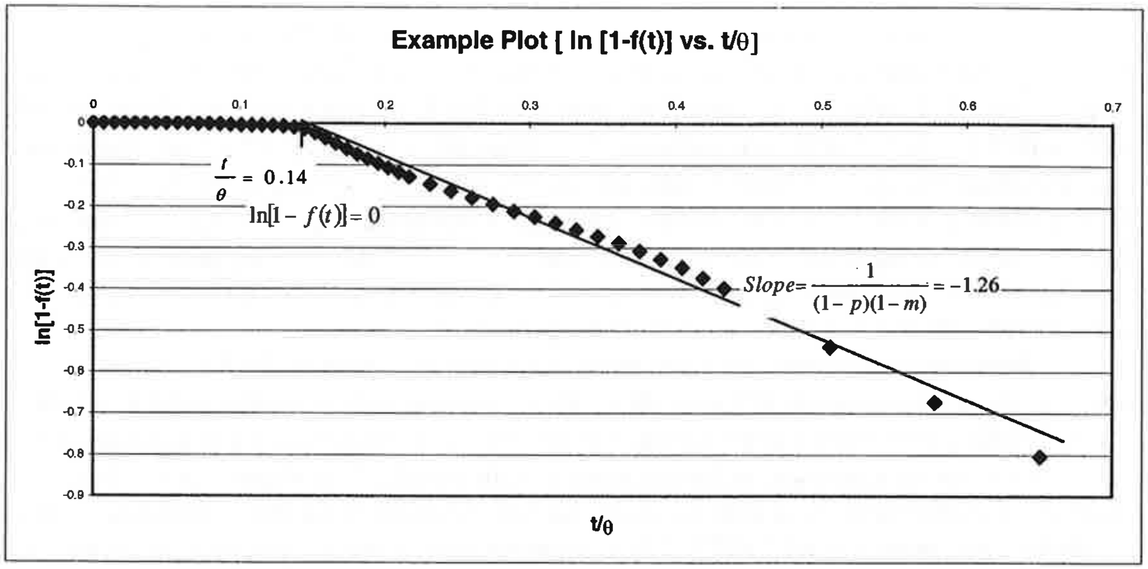


Figure 3. Example of the application of the Rebhun and Argaman analysis procedure.

2.3.2 Scale Model Experiments

Eleven experiments were conducted in triplicate (Table 3). Inflow was kept constant throughout the experiments at 11.9 L/min (0.007 ft.^{3}/s), with the exception of Experiment M11, which was conducted using the Spokane wet pond base flow of 0.02 m^3/sec (0.8 ft^3/sec) scaled to model size, 2.8 L/min (0.10 ft^3/min). Flow into the model was generated using a calibrated, variable speed Masterflex peristaltic pump, (Model 7549-30) fitted with Masterflex 6402-82 tubing. Rhodamine dye was injected directly into the tubing using a hypodermic needle and syringe to limit mixing prior to entrance into the model. Entrance velocity was scaled by the size and slope of the inlet pipe to correspond with the entrance velocity of the prototype.

Two sets of experiments were conducted with the existing Spokane pond configuration, experiments M1 and M11. These experiments were designed to establish the hydraulic performance and mixing characteristics of the existing wet pond and to serve as a basis for comparison for the studies with modified configurations. The data from these experiments was also used to establish parameters for the development of the predictive computer model (DSS). The remaining experiments were performed to gain information regarding the effects of placing inlet baffles on overall mixing characteristics within the pond. A complete description of the other experiments (M2-M10) and their results can be found in Coombs, 1998 (57).

2.4 Sample Collection

2.4.1 Water Samples

Automated flow meter/data loggers and sample collectors (American Sigma 960 flow meter/data logger and American Sigma 900 portable sampler) were installed at the influent and effluent discharge locations at both the Spokane and Vancouver ponds. Each sampling station included a 12-volt battery for power, Motorola 3W cellular telephone (Model 19106NAL8F) and modem, pressure transducer/velocity probes, pH/conductivity probes, and rain gauge. The batteries were recharged with a Solarex solar panel, (model MSX 64). The equipment was housed in two sealed 55-gallon steel drums.

Each station also included a tipping bucket rain gauge (Sigma Model 2149) that recorded each 0.01 inches of rain. Precipitation, flow rate, water temperature, pH, and conductivity were recorded at 2-minute intervals to define storm and inter-storm events as accurately as possible. The data logger also recorded sampling dates and times for each storm event. All data was downloaded remotely using the cell phone – modem system and Sigma Insight (remote connection software).

During rainfall events, pond influent (highway runoff) and pond effluent samples were collected automatically. Discrete water samples were collected based on a pre-selected time interval after sampling was initiated. Sample initiation was triggered when the water depth and the amount of precipitation exceeded predetermined setpoints. These setpoints were changed to reflect weather patterns at different times of the year. Initially the samplers were configured to collect discrete samples in each of 24, 575 mL polyethylene bottles. Later, eight 950 mL glass bottles were used to collect samples for polycyclic aromatic hydrocarbon (PAH) and total petroleum hydrocarbon (TPH) analysis.

Table 3. Scale model experimental conditions for all tracer runs.

Experiment No.	Modification	Flow (L/min)	Volume (L)	Theoretical Residence Time (hr)
M1	None	11.9	1648	2.3
M2	Parallel Baffle	11.9	1648	2.3
M3	30° Baffle	11.9	1648	2.3
M4	60° Baffle	11.9	1648	2.3
M5	Short 60° Baffle	11.9	1648	2.3
M6	5% Island	11.9	1500	2.1
M7	10% Island	11.9	1400	2.0
M8	15% Island	11.9	1300	1.8
M9	Submerged Inlet	11.9	1648	2.3
M10	Angled Submerged Inlet	11.9	1648	2.3
M11	Base Flow	2.8	1523	9.1

Water column samples were collected quarterly over a two-year period. The samples were collected at three locations within the pond: near the inlet structure, near the outlet structure, and in the dead zone area of both the Spokane and Vancouver ponds. Two samples were collected at each site, one approximately 6 cm below the surface and the other approximately 6 cm above the bottom.

2.4.2 Sediment Samples

Sediment cores were collected three times per year from October 1997 to May 1999 in three pond locations. A 5-cm (2-in) diameter sediment corer (stainless steel) was used to collect cores up to 30 cm (12 in) deep, depending on the soil type. During each sampling event, three "replicate" cores were taken from locations near the inlet structure, near the outlet structure, and in the dead zone, an area of little water circulation. The cores were sectioned, when possible, into 10 cm increments and the sections placed in labeled Nalgene containers.

2.4.3 Interstitial Water Samples

Sediment pore-water (interstitial water) was collected using porous cup lysimeters that were place near the inlet, outlet and dead zone of the Vancouver and Spokane pond. Samples were collected from the lysimeters three times per year by placing a Tygon tube down the lysimeter and pumping out the contents with a Nalgene hand vacuum pump (Fisher Scientific) and analyzed for soluble copper, iron, lead, cadmium, and zinc.

2.4.4 Algae Samples

Three times during the summer, samples of algae were taken from the pond at several locations (Figure 4). The three sample sites (S1, S2, and S3) located between the pond inlet and outlet were place in those locations because a significant portion of the inlet flow was observed to travel along this path toward the outlet. Samples were collected by placing a 30.5 cm square frame in the selected area to use as a visual refernce, as the alga from the pond bottom to the surface was extracted and placed in a Nalgene container. Excess water was decanted, and the alga dried. The dry alga was then ground, using a porcelain mortar and pestle, and divided into triplicate samples. Each triplicate sample was acid digested based on a method reported by Havalin and Soultanpout for subsequent ICP analysis to quantify metal concentrations (58).

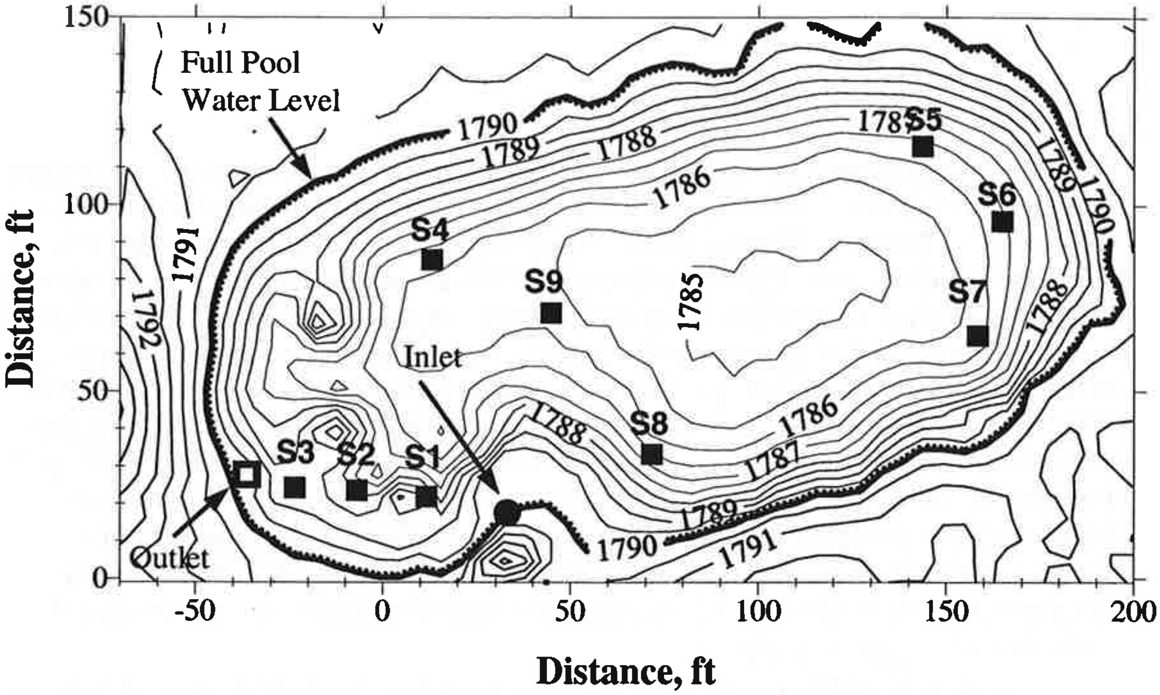


Figure 4. Contour map of the Spokane, Washington wet pond showing the algae sample collection locations.

2.5 Sample Analysis

2.5.1 Water Analysis

Aqueous phase samples were collected and stored according to the procedures specified in *Standard Methods for the Analysis of Water and Wastewater* (hereafter referred to as *Standard Methods*) (59). Analyses for all pond influent and effluent samples included: Total Kjeldahl nitrogen (TKN), ammonia, nitrate, total phosphorus, ortho-phosphorus, total suspended solids, volatile suspended solids, alkalinity, chemical oxygen demand, and total and soluble copper, zinc, cadmium, and lead. Nutrients and solids were analyzed according to the following *Standard Methods* procedures (59): TKN 4500-Norg B. Macro-Kjeldahl, Ammonia 4500-NH3 B. Preliminary Distillation Step and C. Titrimetric Method; Nitrate 4500-NO3E. Cadmium Reduction Method; Total Phosphorus 4500-P B. Sulfuric Acid-Nitric Acid Digestion and E. Ascorbic Acid Method; Ortho-phosphorus 4500-P E. Ascorbic Acid Method; Alkalinity 2320 B. Titration Method; COD 5220 D. Closed Reflux, Colorimetric; TSS 2540 D. Total Suspended Solids at 103-105 °C, and Volatile Suspended Solids 2540 E. Fixed and Volatile Solids Ignited at 550°C.

Total and soluble metals were analyzed according to USEPA Method 200.7 (60). The acid extracts resulting from this procedure were stored at 4 °C prior to inductively coupled argon plasma (ICP) analysis in 50 mL Nalgene bottles. Initially, a Thermo Jarrell Ash ICP spectrophotometer (Model ICAP-61) was used for all metal analyses. Due to the MDL of the Thermo Jarrell Ash ICP (approximately 10 μg/L for Cu, Zn, and Cd and 20 μg/L for Pb) and the generally low metal concentrations present in aqueous phase samples, many storm event and water column sample concentrations were reported as less than MDL. A newly acquired ICP mass spectrometer (ICP-MS) was employed to re-run over 500 samples that were collected during storm events. The Hewlett-Packard ICP-MS (Model 4500 Plus) gave method detection limits (MDLs) for total metal concentrations of: 0.759 μg/L for copper, 2.856 μg/L for zinc, 0.181 μg/L for cadmium, and 0.327 μg/L for lead. For soluble metal concentrations MDLs were: 0.175 μg/L for copper, 2.983 μg/L for zinc, 0.157 μg/L for cadmium, and 0.062 for lead. The MDLs were determined by applying a statistical analysis to ICP/MS data generated from replicate blank samples and replicate samples that covered a range of concentrations (61).

Selected samples (storm event and water column) were also tested for TPH (USEPA Method 418.1), PAH (USEPA Method 8270) and toxicity. Toxicity was tested on a limited number of samples using the 96-hour *Selenastrum capricornutum* (algae) chronic test and the 48-hour *Daphnia magna* acute toxicity test, which were performed at Oregon State University. Additional toxicity data was collected on influent and effluent samples using the Microtox® acute toxicity protocol. The test consisted of exposing the Microtox® test organism, a luminescent marine bacteria *Vibrio fischeri*, to dilutions of a known concentration of the sample. A concentration that was lethal to 50% of the population, which was reported as an effective concentration or EC_{50}, was then calculated.

2.5.2 *Sediment Analysis*

A known mass of sediment was sieved to determine grain size distribution, after drying, through US sieve series number 4, 10, 60, and 200 (62). Sediment retained on the 60 and 200 sieves and sediment passing the 200 sieve was analyzed for metals that included copper, lead, cadmium, zinc, and iron (60). This acid digestion procedure extracts what is sometimes referred to as "available" metals and is not intended to completely digest the sample to assess actual sediment mineralogy. The acid digest solution was placed in 50 mL Nalgene bottles and stored at 4 °C prior to ICP analysis. In addition, percent organic matter was determined for selected sediment samples.

2.6 Statistical Methods

The method selected for characterizing highway runoff and for estimating stormwater pollutant loads in this research was the use of event mean concentration (EMC). This method assumes that constituent concentration is constant within each time step of the simulation and that calculated loads depend only on how well the EMC is estimated and how well storm flows are measured (63). An EMC value represents a flow average concentration computed as the total pollutant load (mass) divided by the total runoff volume (Equation 6).

$$EMC = \overline{C} = \frac{M}{V} = \frac{\int_0^{t_r} c(t)q(t)dt}{\int_0^{t_r} q(t)dt} \tag{6}$$

Where M is the total mass of constituent over the event duration; V is the total volume of water generated during the flow event; $\overline{C}$ is the flow weighted average concentration for the entire event; *c(t)* is the time variable pollutant concentration; *q(t)* is the time variable flow; and *t* is time. For this research, constituents that were present in the runoff samples at concentrations below the MDL were assigned a value of zero during the calculation of EMC values. The concentration flow data was manipulated using MathCAD to calculate the values of EMC.

Correlation coefficients were used to evaluate potential relationships within the observed data. The correlation coefficient, *r*, also known as the Pearson product moment correlation coefficient, is an index of the degree of liner association between two random variables. Mathematically, the correlation coefficient is written as:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2}\sqrt{\sum(y_i - \overline{y})^2}} \tag{7}$$

where: x_i and y_i are individual values of the two random variables, respectively, $\bar{x}$ and $\bar{y}$ are the sample means of the two random variables, respectively, and n is the number of samples. The correlation coefficient is unitless and varies between minus one and plus one, where –1.0 represents a perfect negative correlation and +1.0 is a perfect correlation of the two random variables. An r value of zero indicates that no linear relationship exists between the variables being evaluated (64). A significance test was performed to determine if an observed correlation coefficient was significantly different from zero. When the true correlation is zero, it can be shown that the statistic

$$t^* = r\frac{\sqrt{n-2}}{\sqrt{1-r^2}} \tag{8}$$

has a t-distribution with n-2 degrees of freedom, provided that both variables are normally distributed (64). This is an appropriate test for significance with highway runoff constituents since EMCs vary from one storm to another following a log-normal distribution (27,29,63).

2.7 Predictive Model Development

2.7.1 Flow Simulation

The mass conservation equation was applied to a wet pond system to define outflow. The rate of change of storage in a detention pond can be found by writing a mass balance equation between inflow, outflow and losses for the entire system in the following manner.

$$\Delta V / \Delta t = \bar{I} - \bar{O} - \bar{L} \tag{9}$$

$$\bar{I} = \frac{I_1 + I_2}{2} \tag{10}$$

$$\bar{O} = \frac{O_1 + O_2}{2} \tag{11}$$

$$\bar{L} = \frac{L_1 + L_2}{2} \tag{12}$$

$$\Delta V = V_2 - V_1 \tag{13}$$

where ΔV = change in pond volume (m^3); Δt = time step (sec); $\bar{I}$ = average inflow rate during Δt (m^3/s); $\bar{O}$ = average outflow rate during Δt (m^3/s); $\bar{L}$ = average loss rate during Δt (m^3/s); I_1 = inflow at the beginning of time step (m^3/s); I_2 = inflow at the end of time step (m^3/s); O_1 = outflow at the beginning of time step (m^3/s); O_2 = outflow at the end of time step (m^3/s); L_1 = total loss at the beginning of time step (m^3/s); L_2 = total loss at the end of time step (m^3/s); V_1 = volume at the beginning of time step (m^3); and V_2 = volume at the end of time step (m^3).

For a given time step, I_1, I_2, O_1, and V_1 are known and O_2 and V_2 need to be determined. O_2 can be determined from the storage – outflow relationship. If there is a rectangular weir at the outlet for example, the outflow equation can be written as

$$O_2 = C_w L_e H^{1.5} \tag{14}$$

with

$$C_w = \frac{2}{3} C_d \sqrt{2g} \tag{15}$$

where C_w = weir constant; L_e = effective length of the weir (m); H = head measured above the weir crest level (m); C_d = coefficient of discharge (dimensionless); and g = acceleration due to gravity (m/sec^2) (65).

Substituting all the values in Equation 9, V_2 can be found by

$$V_2 = V_1 + \frac{I_1 + I_2}{2}\Delta t - \frac{O_1 + O_2}{2}\Delta t - \frac{L_1 + L_2}{2}\Delta t \tag{16}$$

2.7.2 Dissolved Constituent Simulation

Considering no reaction in a reactor, the following equation can be used to find the number of CSTRs in series to account for measured or assumed reactor dispersion (50)

$$C = C_o \frac{N(Nt/t_R)^{N-1}}{(N-1)!} e^{-Nt/t_R} \tag{17}$$

with $t_R = \frac{V_{eff}}{Q}$ (18)

where C = effluent concentration at any time (mg/l); C_o = initial concentration (mg/l); t = time (sec); N = number of CSTRs in series; t_R = theoretical residence time (sec); V_{eff} = Effective volume of the reactor (wet pond) or built volume minus dead volume (m^3); Q = average flow to the pond (m^3/s).

It was determined that under a variety of flow and pond configurations, wet ponds behave essentially like a CSTR type reactor with dead volume (a complete discussion of the foundation of this finding can be found in Chapter 4). Considering a CSTR with a first-order reaction, the mass balance equation can be written as

$$\frac{d(VC)}{dt} = I(t)C_i(t) - O(t)C(t) - L(t)C(t) - KC(t)V(t) \tag{19}$$

The above written mass balance equation can be approximated for the time interval Δt as

$$\frac{C_2V_2 - C_1V_1}{\Delta t} = \frac{C_{i_1}I_1 + C_{i_2}I_2}{2} - \frac{C_1O_1 + C_2O_2}{2} - \frac{C_1L_1 + C_2L_2}{2} - K\frac{C_1V_1 + C_2V_2}{2} \tag{20}$$

where C_1 = effluent concentration at the beginning of time step (mg/L); C_2 = effluent concentration at the end of time step (mg/L); C_{i1} = influent concentration at the beginning of time step (mg/L); C_{i2} = influent concentration at the end of time step (mg/L); and K = first order reaction rate constant (sec^{-1}).

From the solution of the flow routing equations, I_1, I_2, O_1, O_2, L_1, L_2, V_1, and V_2 are known. The concentration in the pond at the beginning of the time step, C_1, and the influent concentrations, C_{i1} and C_{i2} are also known. Knowing the first order decay rate, K, the effluent concentration, C_2, can be found by rearranging Equation 20 as

$$C_2 = \frac{C_1V_1 + \frac{(C_{i_1}I_1 + C_{i_2}I_2)}{2}\Delta t - \frac{C_1O_1}{2}\Delta t - \frac{C_1L_1}{2}\Delta t - \frac{KC_1V_1}{2}\Delta t}{V_2\left(1 + \frac{K\Delta t}{2}\right) + \frac{O_2}{2}\Delta t + \frac{L_2}{2}\Delta t} \tag{21}$$

2.7.3 Solids Removal Simulation

Sediment removal was predicted using discrete particle settling theory that is based on Stoke's law. The terminal settling velocity of a discrete particle can be defined as

$$V_s = \sqrt{\frac{4}{3}\frac{gd}{C_D}(S_p - 1)} \tag{22}$$

where V_s = settling velocity of particle (m/sec); d = diameter of particle (m); S_p = specific gravity of particle (dimensionless); and C_D = drag coefficient (dimensionless) (66).

Additionally,

$$C_D = \frac{24}{N_R}\text{, if } N_R < 0.5\text{, or} \tag{23}$$

$$C_D = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34\text{, if } 0.5 \le N_R < 10^4\text{, or} \qquad (24$$

$$C_D \cong 0.4 \text{, if } N_R \geq 10^4 \qquad (25)$$

where

$$N_R = \frac{V_s d}{\nu}. \qquad (26)$$

N_R = Reynolds number (dimensionless); and ν = kinematic viscosity (m^2/sec).

Percent removal of suspended solids is a function of the overflow rate or design settling velocity (66). Surface overflow rate is given by

$$V_o = \frac{Q_o}{A} \qquad (27)$$

where V_o = surface overflow rate (m/sec); Q_o = average outflow from the pond (m^3/s); and A = surface area of the pond (m^2).

Percent solids removal was computed by

$$FR = (1 - F_o) + \frac{1}{V_o} \int_0^{F_o} V_s dF \qquad (28)$$

where FR = Fraction of solids removed; $(1 - F_o)$ = fraction of particles with settling velocity V_s greater than V_o; $\frac{1}{V_o} \int_0^{F_o} V_s dF$ = fraction of particles with settling velocity V_s less than V_o.

2.7.4 Metal Partitioning Model

A linear isotherm model approach was used to correlate the particulate bound solid phase and dissolved liquid phase concentration of each metal. At equilibrium, the linear model is expressed as

$$C_s = K_d C_e \qquad (29)$$

where C_s = equilibrium particulate bound metal element mass (mg/kg of dry solids, TSS); K_d = partition coefficient between solid and dissolved mass (L/kg); and C_e = equilibrium dissolved (liquid phase) concentration of metal (mg/L).

The total metal concentration was written as

$$C_t = C_e + C_s \qquad (30)$$

After accounting for unit inequalities and then rearranging we have

$$C_e = \frac{C_t}{(K_d * TSS_{in} / 10^6 + 1)} \tag{31}$$

where C_t = Concentration of total metal (mg/L); and TSS_{in} = Total suspended solids in the solution (mg/L). Equation 31 was used to calculate the dissolved phase metal concentration knowing C_t, K_d, and TSS_{in}.

Assuming that metals partition on to particles uniformly, regardless of the size, the fraction of particulate bound metal exiting the pond was expressed as

$$C_{se} = (1 - FR) * C_s \tag{32}$$

where C_{se} = solid phase metal concentration in the effluent (mg/L); and FR = total fractional removal of suspended solids.

Therefore, the total metal concentration exiting the pond was written as

$$C_{te} = C_{se} + C_e \tag{33}$$

where C_{te} = total metal concentration in the effluent (mg/L).

Metal removal efficiency was defined as

$$\gamma = \frac{C_t - C_{te}}{C_t} \times 100 \tag{34}$$

where γ = metal removal efficiency (%).

2.7.5 First Order Nutrient Rate Constant Determination

First order rate constants were estimated for the degradation of TKN, NH_3, total phosphorous, ortho phosphorous, and NO_3^- by collecting data utilizing three in-field reactors that were placed in the Spokane wet pond. The reactors were made from clear Plexiglas, and measured 30cm x 30cm x 137cm and were open on each end. Each reactor was placed in the pond by forcing the bottom-end into the pond sediment. The reactors were further secured by attaching them to concrete blocks. This approach was used to simulate actual pond conditions of light and temperature and to afford a means of accounting for any sediment-water column interaction with regard to its affect on nutrient concentration. The reactors were then spiked with highway runoff slurry that was collected by pouring deionized water onto the pavement of SR 195 and extracting the water from the pavement with a hand-held vacuum. This slurry was added to each reactor, the reactor contents mixed and a time zero sample taken for quantification of nutrients. Samples were collected intermittently over a 42-day period for constituent analysis.

The samples nutrient concentration-time data that resulted was used to estimate first order reaction rate constants for each constituent. The standard first order rate equation was integrated and linearized and the data fit using linear regression was used as shown below.

$$\frac{dC}{dt} = -KC$$

$$\int_{C_0}^{C_t} dC = -K \int_{0}^{t} dt \qquad (35)$$

$$\ln C_t - \ln C_0 = -Kt$$

Where C_0 and C_t are constituent concentrations at time zero and t, respectively and K is the first order rate constant. The slope of the least squares best fit line (linear regression) after plotting $\ln(C_t)$ vs t yields K.

3 CHAPTER 3
RESULTS AND DISCUSSION

3.1 Wet Pond Constituent Retention

At the Spokane experimental site, 16 storm events were monitored from September 1997 to April 1999. Of those 16 events, 9 had a full complement of inlet and outlet nutrient and suspended solids data and 7 had a full complement of inlet and outlet metal data. The remainder of the events had inlet data but no corresponding outlet data, a result of insufficient flow in the outlet to trigger the sampler or sample collection device malfunction. During the same time frame, 10 storm events were monitored at the Vancouver site but only 3 could be used for metal removal interpretation.

The data in Table 4 presents the constituent EMCs, mean, standard deviation, and pond removal efficiencies (expressed as a reduction in concentration from the inlet to the pond outlet) for all analyzed runoff constituents for all storm events monitored at the Spokane pond. The data in Table 5 presents the constituent EMC, mean, and standard deviation for monitored events at the Vancouver pond. Because the outlet control structure functioned erratically, making the collection of effluent samples difficult and inconsistent, pond removal efficiency data is not available for the Vancouver site. In general, highway runoff pollutant concentrations entering the Spokane pond were approximately twice those entering the Vancouver pond. This was attributed to the more frequent, smaller storm events occurring in coastally influenced western Washington as compared to the more arid climate of eastern Washington. With less time between runoff events in Vancouver, build up of pollutants on the highway was minimized.

3.1.1 Metals

Driscoll *et al.* (1990) compiled the following median EMC data for total metals from highways with ADT greater than 30,000 vehicles: lead 400 μg/L; zinc 329 μg/L, and copper 54 μg/L (29). In this research, EMCs were determined for both total and soluble lead, zinc, copper, and for total cadmium. For the influent and effluent water at the Spokane pond, the mean EMC for total lead was 58 μg/L and 8 μg/L, respectively, with a mean removal efficiency of 63.3% and a range of 7.1% to 98.7% removal. As expected with the removal of lead from fuel, lead concentrations were much lower than those found in previous decades. The corresponding soluble lead mean EMC was 6 μg/L for both the influent and effluent with a mean removal percentage of –48.47, with a range of –350% to 100%. Only two events, October 9, 1998, and February 16, 1999, had positive removal efficiencies for soluble lead; all other events had zero or negative removals. In comparing the fraction of soluble lead to total lead, soluble lead accounted for 10% of lead in the influent and 75% of lead in the effluent, a result of lower sediment concentration in the pond effluent.

The mean influent EMC at the Vancouver pond was 30 μg/L for total lead and 3 μg/L for soluble lead. While these concentrations were approximately half of those determined for the Spokane runoff, the two means were not statistically different at $\alpha = 0.05$ based on the two-tailed, unequal variance *t*-test.

Total zinc mean EMCs were 489 μg/L for the influent and 122 μg/L for the effluent, in good agreement with that listed by Driscoll *et al. (29).* The influent mean soluble zinc EMC was 53 μg/L, and the effluent mean was 38 μg/L. The mean removal efficiencies were 62.44 % and 41.14 % for total and soluble zinc, respectively, with respective ranges of 8.22% to 92.82% and –9.68% and 57.84%. In comparing the fraction of soluble zinc to total zinc, soluble zinc accounted for 11% of zinc in the influent and 31% of zinc in the effluent. The relatively low percentages of dissolved zinc are in contrast to the findings of Sansalone and Buchberger (1997) who found that 95% of zinc existed in the dissolved state in runoff..

As with the total lead concentrations, the total zinc mean influent EMC in Vancouver was approximately half of that found in Spokane, 228 μg/L. The soluble zinc concentration, however, was slightly higher at 69 μg/L. Neither mean zinc values were statistically different at the $\alpha = 0.05$ level.

Spokane total copper mean EMCs were 63 μg/L for the influent and 13 μg/L for the effluent, again in good agreement with Driscoll *et al.* (29). The mean removal efficiency for total copper was 68.16%, with a range of –14.29% to 92.91%. Soluble copper had a mean influent concentration of 13 μg/L and a mean effluent concentration of 7 μg/L for a mean removal efficiency of 45.41%. The removal efficiency range was 10.00% to 76.92%. In comparing the fraction of soluble copper to total copper, soluble copper accounted for 21% of copper in the influent and 54% of copper in the effluent. As with lead and zinc, the effluent copper concentration was below the Washington state surface water standard. Sansalone and Buchberger (1997) reported that copper existed primarily as a dissolved constituent in highway runoff; our effluent percentage agreed with that assessment (35). Mean EMC values at the Vancouver pond were 30 μg/L for total copper and 9 μg/L for soluble copper. These differences also were not statistically significant.

Total cadmium, a metal not reported by Driscoll *et al* (1990) had the following mean EMCs: 3 μg/L for the influent, 1 μg/L for the effluent, and a removal efficiency of 54.75% for the Spokane site. The range of removal efficiency was 0.00% to 93.75%. The Vancouver influent mean EMC for total cadmium was also 3 μg/L. Soluble cadmium was also tested in each storm event but was consistently below the MDL, and thus, is not report here.

Unlike Mesuere and Fish (1989), the results from the Spokane pond do not show an increase in soluble metal concentration in the fall months due to algae die off (44). However, effluent concentrations of dissolved metals as a percentage of total metals were at least 2.5 times greater than influent concentrations, suggesting that the dominant removal mechanism in the pond was sedimentation. This confirms the work of Characklis and Wiesner who stated that sedimentation alone may not be completely effective for removal of metals from runoff (37). They suggested that the nature and removal efficiency of individual metals may need to be evaluated separately before assessing the potential merits of any stormwater treatment system. The results of this study concur with that assessment. It should be noted, however, that although the dissolved metal fraction was significantly greater in the effluent, the concentrations were well below surface water quality standards.

3.2 Nutrients

3.2.1 Nitrogen

Driscoll *et al.* (1990) listed a median EMC for nitrate and nitrite of 0.76 mg/L for highways with ADT greater than 30,000 vehicles (29). The Spokane pond had a mean nitrate EMC of 3.52 mg/L for the influent and 3.37 mg/L for the effluent, much higher than the value listed by Driscoll *et al.* (1990). The high nitrate concentrations were attributed to the intercepted spring water, which is believed to flow through soils of former septic systems. The mean removal was –16.01%, with a range –113.81% to 64.23% (Figure 5). During the summer months, this pond became almost entirely covered with filamentous algae (*Mougoutia* and *Gomphonema*). With the onset of colder weather, the algae died, likely releasing some nutrients through degradation and decay. As shown in Figure 5, the nitrate removal data followed this growth and decay pattern. Removal efficiency was positive in the warmer months of May through October. The removal efficiency was negative in the colder months of November through April during algal senescence and nutrient release.

In contrast, both TKN and ammonia had positive removal efficiencies at 50.15% and 51.70%, respectively. The range of removal efficiency for TKN was 3.34% to 81.83% and for ammonia was –0.36% to 88.23%. Mean influent TKN EMC was 4.53 mg/L and mean effluent EMC was 1.98 mg/L; mean influent ammonia EMC was 1.50 mg/L and mean effluent EMC was 0.62 mg/L. The effluent ammonia concentrations were below the Washington state surface water quality standard of 735 μg/L. TKN, ammonia, and nitrate runoff concentrations were elevated with respect to the natural spring water entering the pond. The spring water had a TKN concentration of 2.4 mg/L, an ammonia concentration of 0.43 mg/L, and a nitrate concentration of 3.9 mg/L. The most likely source of nitrogen-based nutrients was fertilizer applied to right-of-ways and median natural ground covers.

The mean EMCs for nitrogen-based nutrients in the Vancouver influent were 3.402 mg/L for TKN, 1.019 mg/L for ammonia, and 1.889 mg/L for nitrate. All concentrations were lower in the Vancouver runoff as compared to the Spokane runoff, but none were statistically different at the $\alpha = 0.05$ level.

3.2.2 Phosphorus

As shown in Figure 6, phosphorus-based nutrients had no clearly discernable pattern as compared to the nitrogen-based nutrients. The mean EMC for Spokane influent total phosphorus was 0.5 mg/L and for ortho-phosphorus was 0.082 mg/L. The mean EMC for effluent total phosphorus was 0.2 mg/L and for ortho-phosphorus was 0.080 mg/L. Overall average removal efficiencies were 29.31% for total phosphorus, with a range of –143.52% to 84.70%, and 1.03% for ortho-phosphorus, with a range of –92.86% to 69.66%. The influent values for both total phosphorus and ortho-phosphorus were higher during storm events than background concentrations coming from the natural groundwater springs. The springs had an average total phosphorus concentration of 0.19mg/L and ortho-phosphorus concentration of 0.16 mg/L. As with the nitrogen-based nutrients, the most likely source of phosphorus-based nutrients was fertilizer.

Mean influent EMCs in Vancouver were 0.398 mg/L for total phosphorus and 0.018 mg/L for ortho-phosphorus. These nutrient concentrations were also lower than those found in Spokane, but again were not statistically significant at $\alpha = 0.05$.

It is important to note that observed nutrient removals based on EMC could be an artifact of simple dilution that occurs as storm water enters a wet pond with higher concentration than the existing constituent concentration within the pond. This "observed" concentration reduction would be exacerbated if the in-pond constituent concentration is low and the runoff concentration is high, after a relatively long antecedent dry period, for example. This dilution affect will be pointed out later in a section pertaining to numerical model simulation (Section 3.7.2).

3.3 Other Parameters

Total suspended solids and volatile suspended solids had the highest removal rates of all analyzed constituents, with 74.18% of TSS and 64.82% of VSS removed by the Spokane wet pond. Removal efficiency ranged from –6.05% to 99.39% for TSS and from 7.99% to 95.51% for VSS. For highways with an ADT greater than 30,000, Driscoll *et al.* (1990) compiled median EMC data of 142 mg/L for TSS and 39 mg/L for VSS. At the Spokane pond, for all events the mean influent EMC for TSS was 255 mg/L and for VSS it was 59 mg/L. The high mean TSS EMC was not surprising considering that sand and gravel application was used during the winter to improve road conditions. For all events the mean effluent EMC for TSS was 31 mg/L and for VSS was 11 mg/L.

In Vancouver, the mean influent EMC for TSS was 195 mg/L and for VSS was 66 mg/L. These differences were not significant at the $\alpha = 0.05$ level. The Vancouver site was expected to have a lower mean EMC for TSS. Vancouver had a more temperate climate with less snow producing storm events, requiring less sand and gravel application on major thoroughfares.

Alkalinity had a mean influent EMC of 88 mg/L and a mean effluent EMC of 108 mg/L, yielding a negative mean removal efficiency of –29.67%, with a range from –94.01% to 30.68%. The larger effluent value was most likely the result of the groundwater springs intercepted by the pond. The average alkalinity of incoming spring water was 132 mg/L. The less alkaline highway runoff diluted the pond water to a small degree but not enough to offset the naturally alkaline spring water that was constantly entering the pond. Alkalinity in the runoff to the Vancouver site was considerably lower, 23 mg/L, as compared to the Spokane site. The large difference, however, was not statistically significant. As evidenced by the Spokane effluent concentration, the groundwater springs were the major contributors to this difference.

Chemical oxygen demand had a mean influent EMC of 172 mg/L and a mean effluent EMC of 45 mg/L, resulting in a removal efficiency of 55.12%, with a range of –62.42% to 93.90%. The median EMC value reported by Driscoll *et al.* (1990) was 114 mg/L. The average COD of nonrunoff incoming water was 26 mg/L, more than six times less than the incoming runoff. From the effluent data, it was apparent that the runoff water is sufficiently high in COD to elevate the concentration in the exiting pond water. Vancouver runoff had a mean EMC of 156 mg/L, again not statistically different from Spokane runoff.

3.3.1 PAH

Results of the PAH analyses are summarized in Table 8 through Table 9. It can be seen that the most common PAH compounds detected were pyrene, fluoranthene, phenanthrene, and benzo(a)anthracene, the PAHs emitted by automobiles (40). It should be noted that no PAHs were detected above the MDL in either pond effluent.

3.3.2 Toxicity

As shown in Table 5, highway runoff from selected events was tested for toxicity using algae (*S. capricornutum*) and *D. magna* as previously described. One test sample exhibited mild acute toxicity from the Vancouver pond effluent. Of the 13 samples tested, this was the only one to exhibit any acute toxicity. Seven of the 13 samples exhibited mild toxicity in the chronic test with *S. capricornutum*. The Microtox testing protocol also yielded mildly toxic results with an EC50 (15 minute exposure) of 60% for the Spokane inlet sample collected on 9/9/98. Two of the three Spokane events that produced toxic results, September 9, 1998 and September 16, 1998, also had positive results in PAH testing. However, the third Spokane event that tested positively for PAHs, February 19, 1999, resulted in no toxic effects for *D. magna*. More research is needed in this area to determine which pollutants or combinations of pollutants are producing toxic effects in these aquatic organisms.

Table 4. Constituent EMCs and Spokane pond pollutant removal efficiencies.

Event Date	Total Lead EMC (µg/L)			Total Zinc EMC (µg/L)			Total Cadmium EMC (µg/L)			Total Copper EMC (µg/L)		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
26-May-98	14	13	7.1	146	134	8.2	1	1	0.0	24	19	20.8
9-Oct-98	194	17	91.2	1267	230	81.8	16	1	93.8	209	23	89.0
13-Oct-98	7	No data	No data	108	No data	No data	1	No data	No data	13	No data	No data
20-Nov-98	58	No data	No data	507	No data	No data	2	No data	No data	52	No data	No data
25-Nov-98	21	14	33.3	292	190	34.9	1	1	0.0	29	16	44.8
7-Dec-98	16	3	81.3	341	120	64.8	1	0	100.0	42	9	78.6
16-Jan-99	51	No data	No data	387	No data	No data	0	No data	No data	51	No data	No data
16-Feb-99	155	2	98.7	1211	87	92.8	5	1	80.0	141	1	99.3
25-Mar-99	54	1	98.1	506	52	89.7	0	0	#DIV/0!	20	9	55.0
3-Apr-99	9	6	33.3	122	43	64.8	1	1	0.0	7	7	0.0

Event Date	Soluble Lead EMC (µg/L)			Soluble Zinc EMC (µg/L)			Soluble Copper EMC (µg/L)		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
26-May-98	1	2	-100.0	102	43	57.8431373	13	3	76.9
9-Oct-98	8	6	25.0	96	100	-4.1666667	13	10	23.1
13-Oct-98	7	No data	No data	47	No data	No data	9	No data	No data
20-Nov-98	7	No data	No data	33	No data	No data	7	No data	No data
25-Nov-98	7	7	0.0	31	34	-9.6774194	8	7	12.5
7-Dec-98	7	7	0.0	113	49	56.6371681	27	8	70.4
16-Jan-99	7	No data	No data	23	No data	No data	13	No data	#VALUE!
16-Feb-99	7	0	100.0	22	0	100	18	0	100.0
25-Mar-99	2	9	-350.0	29	17	41.3793103	10	9	10.0
3-Apr-99	7	7	0.0	37	20	45.9459459	12	9	25.0

Event Date	TKN EMC (mg/L)			Ammonia EMC (mg/L)			Nitrate EMC (mg/L)		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
14-Sep-97	5.69	1.93	66.1	1.39	0.16	88.2	5.01	4.52	9.76
26-Oct-97	0.80	0.15	81.8	0.48	0.15	69.1	4.43	2.60	41.26
13-May-98	5.92	2.11	64.4	1.33	0.40	69.5	2.82	2.49	11.91
26-May-98	1.02	0.98	3.3	0.27	0.28	-0.4	3.95	1.41	64.23
9-Sep-98	8.31	No data	No data	1.66	No data	No data	3.94	No data	No data
16-Sep-98	6.18	No data	No data	2.38	No data	No data	4.77	No data	No data
9-Oct-98	11.46	6.18	46.1	3.30	2.63	20.4	No data	No data	No data
13-Oct-98	2.76	No data	No data	3.45	No data	No data	4.14	No data	No data
5-Nov-98	3.25	1.95	40.0	0.70	0.40	42.9	1.92	4.10	-113.81
20-Nov-98	No data	No data	No data	No data	No data	No data	No data	No data	No data
25-Nov-98	No data	No data	No data	No data	No data	No data	No data	No data	No data
7-Dec-98	3.71	2.36	36.5	0.43	0.17	60.1	1.91	1.68	11.98
16-Jan-99	No data	No data	No data	No data	No data	No data	No data	No data	No data
16-Feb-99	No data	No data	No data	No data	No data	No data	No data	No data	No data
25-Mar-99	3.45	1.23	64.4	1.64	0.78	52.4	3.54	5.76	-62.80
3-Apr-99	1.80	0.92	48.6	0.91	0.62	31.8	2.30	4.39	-90.62

Event Date	Total Phosphorus EMC (mg/L)			Ortho Phosphorus EMC (mg/L)			Total Suspended Solids EMC (mg/L)			Volatile Suspended Solids EMC (mg/L)		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
14-Sep-97	0.68	0.21	69.2	0.13	0.18	-38.3	172.75	10.11	94.1	No data	No data	No data
26-Oct-97	0.11	0.26	-143.5	0.17	0.10	41.3	9.60	2.71	71.8	No data	No data	No data
13-May-98	1.01	0.20	79.9	0.09	0.03	69.7	521.82	54.92	89.5	86.22	14.33	83.4
26-May-98	0.23	0.14	38.4	0.09	0.06	30.8	30.20	32.03	-6.0	13.53	12.45	8.0
9-Sep-98	0.46	No data	No data	0.06	No data	No data	697.45	No data	No data	126.50	No data	No data
16-Sep-98	0.57	No data	No data	0.01	No data	No data	209.79	No data	No data	62.68	No data	No data
9-Oct-98	0.85	0.19	77.7	No data	No data	No data	559.44	118.42	78.8	114.31	27.76	75.7
13-Oct-98	0.25	No data	No data	0.06	No data	No data	83.44	No data	No data	28.21	No data	No data
5-Nov-98	0.23	0.07	70.6	0.01	0.03	-92.9	188.48	10.22	94.6	67.62	8.18	87.9
20-Nov-98	No data	No data	No data	No data	No data	No data	143.01	No data	No data	33.76	No data	No data
25-Nov-98	No data	No data	No data	No data	No data	No data	124.15	24.49	80.3	23.39	6.01	74.3
7-Dec-98	0.11	0.07	29.5	0.10	0.06	37.5	87.59	27.91	68.1	13.22	3.72	71.9
16-Jan-99	No data	No data	No data	No data	No data	No data	525.07	No data	No data	55.46	No data	No data
16-Feb-99	No data	No data	No data	No data	No data	No data	1850.00	11.24	99.4	88.38	3.97	95.5
25-Mar-99	0.88	0.13	84.7	0.12	0.08	30.2	459.28	16.49	96.4	62.90	6.19	90.2
3-Apr-99	0.13	0.19	-42.7	0.06	0.10	-70.0	37.93	7.44	80.4	11.14	7.05	36.7

Event Date	COD EMC (mg/L)			Alkalinity EMC (mg/L)		
	Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
14-Sep-97	159.0	56.5	64.5	83.3	148.1	-77.7
26-Oct-97	23.6	38.3	-62.4	119.8	118.3	1.3
13-May-98	249.3	33.6	86.5	68.6	96.0	-39.9
26-May-98	55.9	34.6	38.2	103.8	72.0	30.7
9-Sep-98	337.4	No data	No data	61.6	No data	No data
16-Sep-98	268.5	No data	No data	83.8	No data	No data
9-Oct-98	330.4	163.9	50.4	No data	No data	No data
13-Oct-98	101.2	No data	No data	110.9	No data	No data
5-Nov-98	193.1	13.2	93.1	62.7	104.6	-66.7
20-Nov-98	No data	No data	No data	No data	No data	No data
25-Nov-98	No data	No data	No data	No data	No data	No data
7-Dec-98	86.8	43.0	50.4	91.3	90.7	0.6
16-Jan-99	No data	No data	No data	No data	No data	No data
16-Feb-99	No data	No data	No data	No data	No data	No data
25-Mar-99	217.8	13.3	93.9	127.5	116.8	8.4
3-Apr-99	42.2	7.8	81.4	59.2	114.9	-94.0

Table 5. Constituent EMCs and Vancouver wet pond pollutant removal efficiencies.

Event Date	Total Lead EMC (µg/L)	Total Zinc EMC (µg/L)	Total Cadmium EMC (µg/L)	Total Copper EMC (µg/L)
June 15, 1998	No data	No data	No data	No data
October 27, 1998	36	338	3	47
November 19, 1998	32	306	4	37
December 27, 1998	16	230	2	24
January 9, 1999	No data	No data	No data	No data
January 12, 1999	No data	No data	No data	No data
January 17, 1999	13	86	4	17
February 2, 1999	47	233	2	35
February 22, 1999	20	172	2	21
March 28, 1999	No data	No data	No data	No data

Event Date	Soluble Lead EMC (µg/L)	Soluble Zinc EMC (µg/L)	Soluble Copper EMC (µg/L)
June 15, 1998	No data	No data	No data
October 27, 1998	nd	160	20
November 19, 1998	8	56	13
December 27, 1998	nd	89	8
January 9, 1999	No data	No data	No data
January 12, 1999	No data	No data	No data
January 17, 1999	7	25	6
February 2, 1999	nd	45	3
February 22, 1999	nd	41	4
March 28, 1999	No data	No data	No data

Event Date	TKN EMC (mg/L)	Ammonia EMC (mg/L)	Nitrate EMC (mg/L)
June 15, 1998	2.227	0.241	0.688
October 27, 1998	6.560	2.610	No data
November 19, 1998	No data	0.884	1.804
December 27, 1998	No data	No data	No data
January 9, 1999	No data	No data	No data
January 12, 1999	No data	No data	No data
January 17, 1999	No data	No data	0.174
February 2, 1999	No data	No data	No data
February 22, 1999	1.420	0.340	2.775
March 28, 1999	No data	No data	4.002

Event Date	Total Phosphorus EMC (mg/L)	Ortho Phosphorus EMC (mg/L)	Total Suspended Solids EMC (mg/L)	Volatile Suspended Solids EMC (mg/L)
June 15, 1998	0.384	0.006	184.34	52.60
October 27, 1998	0.665	0.005	180.00	No data
November 19, 1998	0.354	0.010	127.12	69.66
December 27, 1998	No data	No data	No data	No data
January 9, 1999	No data	No data	130.53	47.09
January 12, 1999	No data	No data	508.73	147.18
January 17, 1999	0.106	0.008	47.00	15.38
February 2, 1999	No data	No data	208.00	43.30
February 22, 1999	0.483	0.029	104.00	36.00
March 28, 1999	No data	0.051	268.14	115.03

Event Date	COD EMC (mg/L)	Alkalinity EMC (mg/L)
June 15, 1998	94.00	7.72
October 27, 1998	221.93	14.91
November 19, 1998	172.75	39.38
December 27, 1998	No data	No data
January 9, 1999	No data	No data
January 12, 1999	No data	No data
January 17, 1999	17.56	11.78
February 2, 1999	No data	No data
February 22, 1999	147.31	2.21
March 28, 1999	282.16	64.43

Table 6. Washington State surface water quality standards.

Constituent	Influent (:g/L)	Effluent (:g/L)
Ammonia	735	735
Cadmium	11	6
Copper	46	27
Lead	199	108
Zinc	280	171

Table 7. PAH analysis for both the Spokane and Vancouver ponds (stormwater samples) ranked in decreasing order of occurrence (concentration expressed as µg/L).

Sample ID	SICOM1	SICOM2	SICOM3	SICOM1	SICOM3	SICOM2	VICOM	VICOM	VICOM	VICOM	VICOM	VICOM1	SICOM1	SICOM2	VICOM	SICOM2	SICOM3	VICOM2	SICOM1	
Sample date	2/18/1999	2/18/1999	2/18/1999	9/9/1998	9/9/1998	9/9/1998	11/19/1998	1/17/1999	4/21/1999	6/15/1998	6/15/1998	3/29/1999	12/17/1997	12/17/1997	5/17/1998	9/16/1998	9/16/1998	3/29/1999	9/16/1998	# of samples > MDL
Pyrene	2.3	2.4	2.2	0.68	0.29	0.56	0.76	0.51	0.57	0.14	0.14	0.21	0.49	0.42	0.16	0.26	.22	0.23	nd	18
Phenanthrene	1.1	1.2	1.1	0.56	0.18	0.43	0.37	0.17	0.23	0.14	0.14	nd	0.19	0.15	nd	0.39	0.23	nd	0.13	16
Fluoranthene	1	1.3	1.2	0.48	0.24	0.39	0.66	0.37	0.54	0.13	0.13	0.19	nd	nd	0.16	0.29	0.16	0.2	nd	16
Chrysene	2.5	2.7	2.3	0.92	0.52	0.58	0.42	0.21	0.48	0.11	0.11	nd	0.47	nd	0.12	nd	nd	nd	nd	13
Benzo(a)anthracene	0.54	0.52	0.53	nd	nd	nd	0.29	0.16	0.22	nd	nd	0.15	nd	nd	nd	nd	nd	0.16	nd	8
Naphthalene	0.12	0.18	0.18	0.75	0.86	0.73	0.45	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	7
2-Methylnapthalene	0.13	0.18	0.17	0.95	1	0.94	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	6
Benzo(b)fluoranthene	0.58	0.56	0.42	nd	nd	nd	nd	0.16	nd	nd	nd	nd	nd	0.12	nd	nd	nd	nd	nd	5
Anthracene	0.11	0.13	0.13	nd	0.19	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4
Fluorene	0.13	0.18	0.18	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3
Benzo(k)fluoranthene	0.13	0.22	0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3
Benzo(a)pyrene	0.92	1	0.95	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3
Benzo(g,h,i)perylene	nd	nd	nd	0.33	nd	nd	nd	nd	nd	nd	nd	0.2	nd	nd	nd	nd	nd	nd	nd	2
2-Chloronapthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0
Acenapthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0
Acenapthene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0
Indeno(1,2,3-cd)pyrene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0
Dibenz(a,h)anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0
# of samples > MDL	12	12	12	7	7	6	6	6	5	4	4	4	3	3	3	3	3	3	1	

Table 8. PAH data for the Vancouver pond (water column samples) ranked in decreasing order of occurrence (concentration expressed as μg/L).

Sample ID	CLUP	VEWCB	VDWCB	VIWCB	VIWCB	VDWCT	VIWCT	VDWCB	VEWCB	VIWCB	VIWCB	SIWCB	VDWCT	SDWCT	VIWCT	VIWCT	VDWCB	SEWCB	VDWCT	VEWCT	VIWCT	VIWCB	SEWCB
Sample date	3/20/1999	3/23/1998	3/23/1998	1/17/1999	9/27/1998	3/23/1998	1/17/1999	1/17/1999	1/17/1999	3/28/1999	3/23/1998	1/12/1999	1/17/1999	1/31/1998	3/23/1998	5/17/1998	9/27/1998	3/16/1998	11/19/1998	1/17/1999	3/28/1999	11/25/1997	1/31/1998
Pyrene	1400	1.4	1.1	0.53	0.48	0.47	0.57	0.41	0.37	0.31	0.33	0.63	0.31	0.16	0.3	0.21	0.15	0.29	0.25	0.25	0.22	0.11	0.16
Fluoranthene	1600	1	0.82	0.56	0.27	0.37	0.47	0.35	0.33	0.22	0.23	0.26	0.26	0.19	0.3	0.21	nd	nd	0.25	0.23	0.18	0.11	0.13
Phenanthrene	690	0.38	0.31	0.31	nd	0.25	0.29	0.21	0.15	0.13	nd	0.33	0.17	0.15	0.12	0.11	0.14	nd	0.11	0.12	nd	0.13	nd
Benzo(a)anthracene	640	0.57	0.74	0.33	nd	0.27	0.17	0.12	0.1	0.13	0.18	0.16	0.12	0.15	0.17	0.21	nd	0.33	0.15	nd	nd	nd	0.17
Benzo(b)fluoranthene	1100	1.1	0.87	0.31	0.48	0.32	0.28	0.17	0.2	0.22	0.26	0.14	nd	nd	nd	0.19	0.16	0.15	nd	nd	0.11	nd	nd
Chrysene	1100	1.1	0.55	0.27	0.23	0.42	0.37	0.21	0.26	0.13	0.3	0.42	0.19	nd	0.24	nd	nd	nd	nd	0.14	0.13	nd	nd
2-Methylnapthalene	920	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.3	nd	nd	nd	nd	nd	nd
Naphthalene	1200	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.22	nd	nd	nd	nd	nd	nd
Benzo(g,h,i)perylene	nd	0.61	0.61	0.2	0.3	nd	nd	0.11	0.19	0.22	nd	nd	0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(a)pyrene	720	0.88	0.56	0.21	0.26	nd	0.21	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.17	nd	nd	nd	nd	nd
Benzo(k)fluoranthene	210	0.23	0.15	nd	0.28	nd	nd	nd	nd	nd	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	nd	0.55	nd	0.21	0.27	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Anthracene	100	nd	nd	nd	nd	0.15	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenapthene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fluorene	110	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dibenz(a,h)anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.15	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Chloronapthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenapthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
# Samples > MDL	12	10	9	9	8	7	7	7	7	7	6	6	6	5	5	5	5	4	4	4	4	3	3

Table 9. PAH data for the Spokane pond (water column samples) ranked in decreasing order of occurrence (concentration expressed as μg/L).

Sample ID	SIWCT	SDWCB	VEWCT	VDWCB	VDWCT	VEWCT	VDWCB	SIWCT	VIWCB	SIWCB	SIWCT	SIWCB	SEWCT	SEWCB	SEWCB	VDWCT	SIWCB	SEWCB	VIWCT	VDWCT	VDWCB	SDWCB	SEWCB
Sample date	3/16/1998	3/16/1998	3/23/1998	5/17/1998	9/27/1998	9/27/1998	3/28/1999	12/10/1997	1/25/1998	1/31/1998	11/11/1998	11/11/1998	11/11/1998	11/11/1998	1/12/1999	3/28/1999	12/10/1997	12/10/1997	1/25/1998	1/25/1998	1/25/1998	5/23/1998	5/23/1998
Pyrene	nd	0.26	0.33	0.14	nd	nd	0.22	nd	0.15	0.1	nd	nd	nd	nd	0.23	0.21	nd	0.11	0.12	nd	0.15	nd	0.1
Fluoranthene	nd	0.1	0.24	0.14	0.12	nd	0.18	nd	0.13	nd	nd	nd	nd	nd	nd	0.15	nd	nd	nd	0.11	nd	nd	nd
Phenanthrene	nd	nd	0.12	nd	0.12	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	nd	0.2	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	nd	nd	nd	0.1	nd	nd	0.13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chrysene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.29	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylnapthalene	0.29	nd	nd	nd	0.11	2.4	nd	0.083	nd	nd	0.36	0.45	0.7	0.11	nd	nd	0.066	nd	nd	nd	nd	nd	nd
Naphthalene	4.1	nd	nd	nd	nd	1.7	nd	0.083	nd	nd	2.2	3.1	6	0.19	nd	nd	nd	nd	nd	nd	nd	0.093	nd
Benzo(g,h,i)perylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(a)pyrene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(k)fluoranthene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenapthene	0.17	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dibenz(a,h)anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Chloronapthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenapthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
# Samples > MDL	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1

Table 10. Highway runoff chronic and acute toxicity results (NTE: not toxic affect.

Sample ID	Sample location	Pond Location	Sample type	Sample date	*Selenastrum capricornutum* EC50 (%)	*Dafnia. magna* EC50 (%)
SICOM1	Spokane	influent	storm	10/2/1997	NTE	NTE
SICOM2	Spokane	influent	storm	10/2/1997	NTE	NTE
VICOM	Vancouver	influent	storm	3/1/1998	NTE	NTE
VECOM	Vancouver	effluent	storm	3/1/1998	NTE	NTE
SICOM	Spokane	influent	storm	9/9/1998	47	NTE
SICOM	Spokane	influent	storm	9/16/1998	71	NTE
SICOM	Spokane	influent	storm	12/07/98	78	NTE
VICOM	Vancouver	influent	storm	2/2/1999	75	NTE
VECOM	Vancouver	effluent	storm	2/2/1999	70	NTE
SICOM	Spokane	influent	storm	2/18/1999	NTE	NTE
SECOM	Spokane	effluent	storm	2/18/1999	77	NTE
VICOM	Vancouver	influent	storm	2/22/1999	NTE	NTE
VECOM	Vancouver	effluent	storm	2/23/1999	37	27

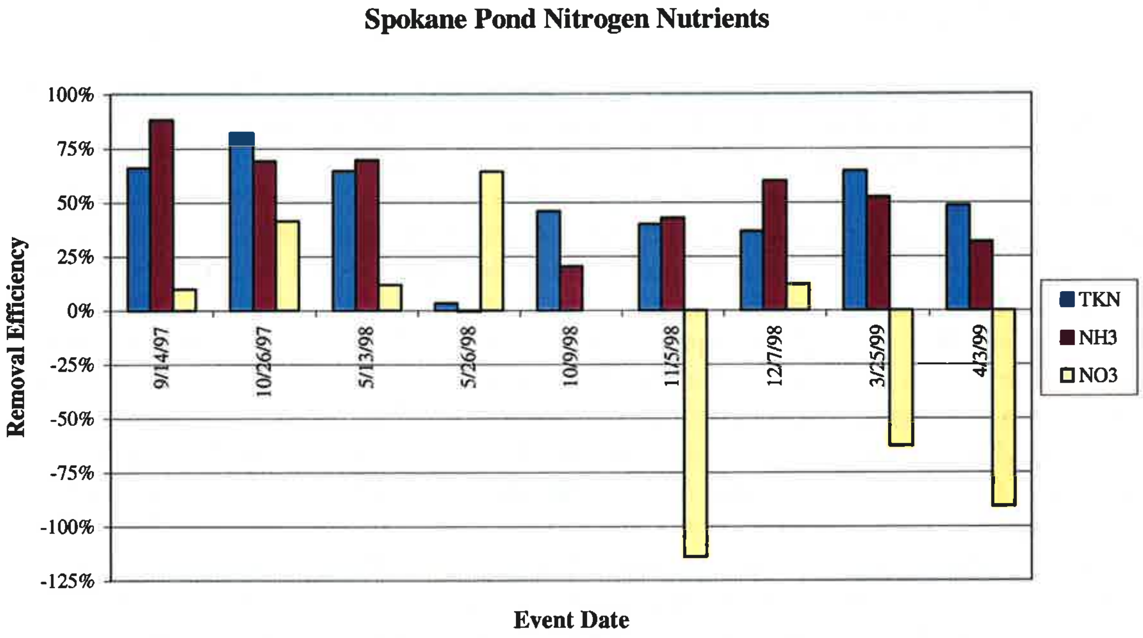


Figure 5. Spokane pond nitrogen-based nutrients removal efficiencies.

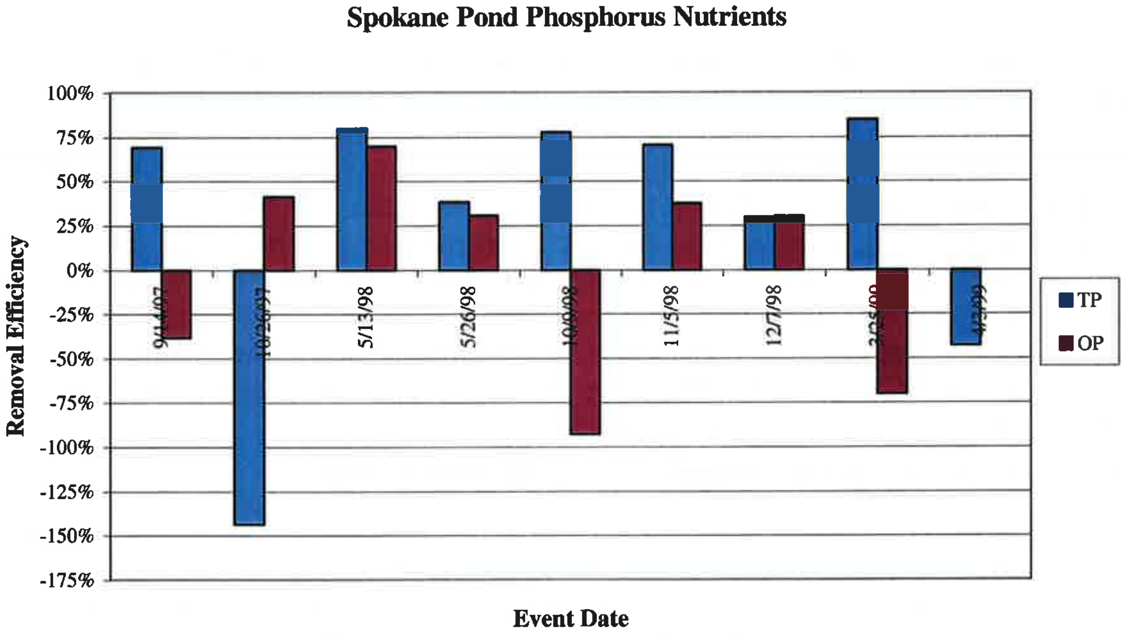


Figure 6. Spokane pond phosphorus-based nutrients removal efficiencies.

3.4 First Flush

First flush refers to the delivery of a disproportionately large load of constituents during the early part of the runoff hydrograph and is defined as existing when the dimensionless normalized mass is greater than the dimensionless normalized flow volume (23). Figure 7 is a graphic example of this definition for an October 9, 1998 storm event in Spokane for total metals. Conversely, little or no first flush phenomenon was observed for soluble metals (Figure 8) since the metal loading lines plotted near the y=x line. This pattern was present in two other storm events, November 25, 1998, and February 16, 1999. With the exception of the December 7, 1998 event, which did not exhibit a first flush for total or soluble metals, all of the winter events followed this same pattern of a total metal first flush but no first flush of soluble metals.

Highway runoff into the Vancouver pond exhibited a definitive first flush in only one event, June 15,1998. Because of the Mediterranean climate, it was unusual to have a runoff-producing event during the summer months. Particulate matter and other pollutants accumulated over long durations not only on road surfaces but also in the atmosphere. This summer storm had a disproportionately large amount of pollutant build up, and consequently introduced a significant first flush of material into the pond.

The more typical first flush behavior was minimal to nonexistent. First flush was not expected to be of significance in Vancouver because of the small, frequent rain patterns characteristic of coastal climates.

3.5 Scale Model Tracer Testing

Eleven sets of dye studies were conducted in the scale model of the Spokane wet pond. These studies were designed to determine the hydraulic performance of the existing configuration, as well as to assess the effects of baffles, islands and inlet submergence on hydraulic performance. Here, we point out the primary results of these studies as they relate to the selection and development of the predictive model that was used within the DSS. The results of the model experiments are summarized in Table 11. All concentration values have been normalized (C/C_0) to allow for direct comparisons. C is the concentration of the given sample and C_0 is the concentration within the pond assuming a completely mixed homogeneous system (mass added/pond volume). The values given for % CSTR and % Plug Flow are based on the "live" storage fraction of the pond (i.e. pond volume minus "dead" storage).

3.5.1 Results of Model Experiments without Modification

The hydraulic performance of the existing pond (no modification to the inlet) can be explained visually by examining a series of time lapsed photographs as shown in Figure 10. Upon injection, the dye traveled across the surface of the pond with little or no apparent vertical mixing. When the dye reached the opposite side, the flow path

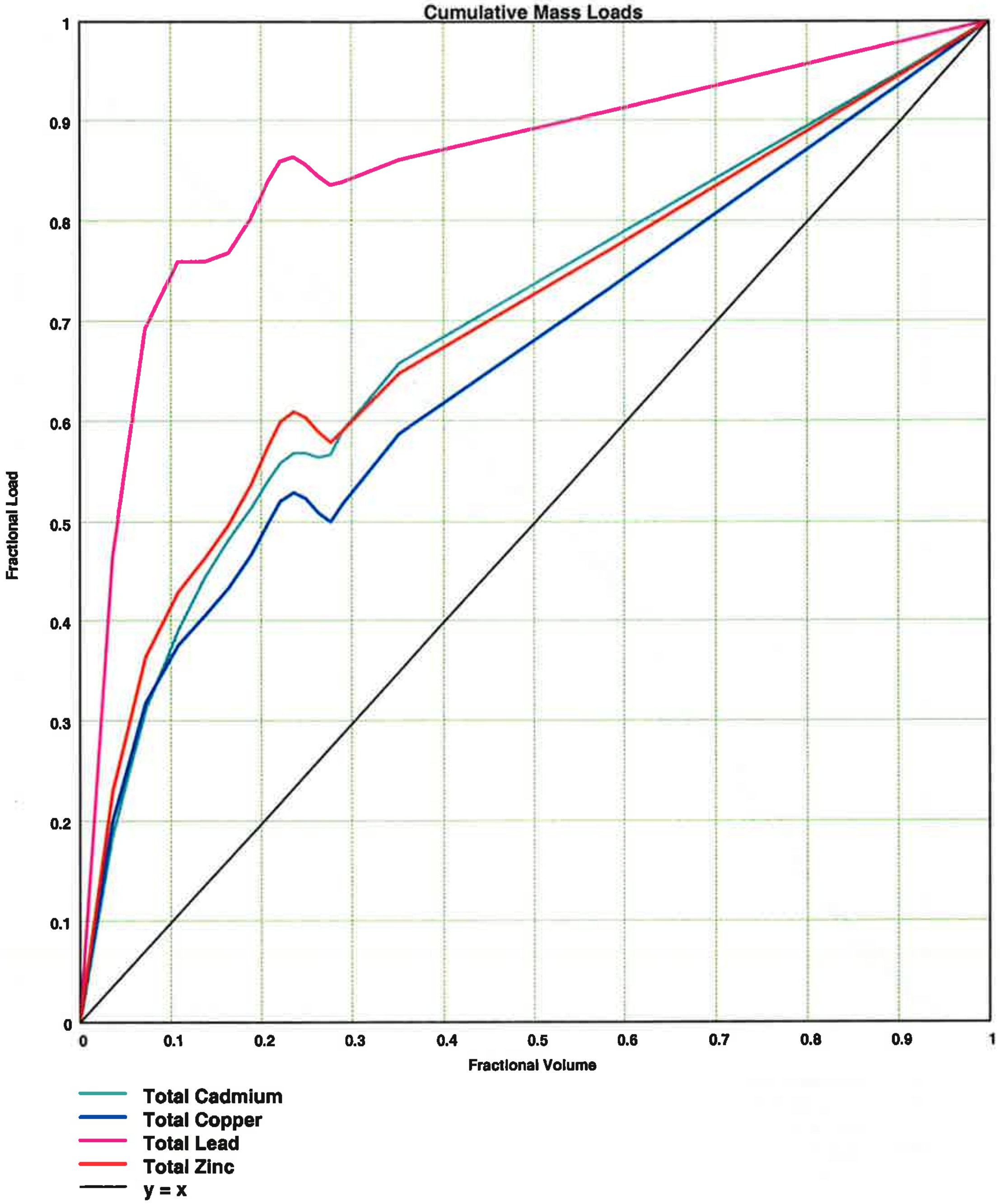


Figure 7. October 9, 1998 Storm Event Cumulative Total Metals Loading Curves

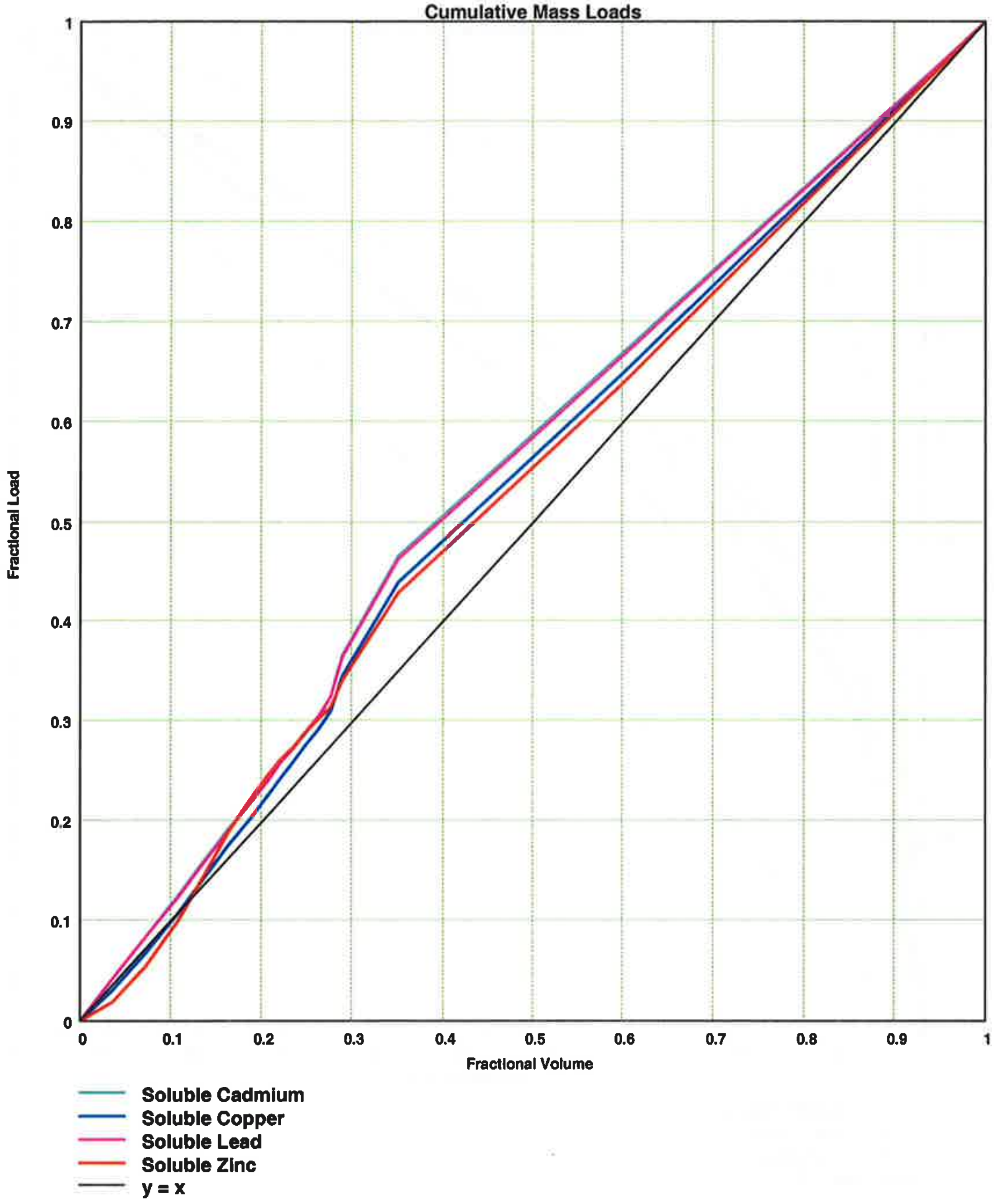


Figure 8. October 9, 1998 storm event cumulative soluble metals loading curves.

Table 11. Summary of the scale model tracer testing; means of triplicate runs for each configuration and confidence intervals ($\alpha=0.05$) are presented. The field result is from a single tracer test event.

Exp #	Configuration	Mean Peak (C/C0)	Mean $\theta^{actual}/\theta^{theoretical}$	Mean % Dead Volume	Mean % V_e Plug Flow	Mean % V_e CSTR
M1	No Modification	1.86 (+/- 0.21)	0.64 (+/- 0.02)	38.33 (+/- 2.11)	3.33 (+/- 080)	96.66 (+/- 0.80)
M2	Parallel Baffle	2.80 (+/- 0.14)	0.56 (+/- 0.02)	44.67 (+/- 2.88)	4.33 (+/- 0.80)	95.67 (+/- 0.80)
M3	30° Baffle	1.57 (+/- 0.08)	0.67 (+/- 0.02)	33.00 (+/- 1.39)	16.67 (+/- 4.00)	83.33 (+/- 4.00)
M4[a]	60° Baffle	2.67 (+/- 2.09)	0.55 (+/- 0.23)	43.33 (+/- 25.00)	29.67 (+/- 3.20)	70.33 (+/- 3.20)
M5	60° Short Baffle	1.37 (+/- 0.08)	0.79 (+/- 0.02)	6.00 (+/- 1.39)	15.67 (+/- 0.80)	84.33 (+/- 0.80)
M6	5% Surface Area Island	5.10 (+/- 0.14)	0.59 (+/- 0.03)	42.67 (+/- 2.88)	4.33 (+/- 0.80)	95.66 (+/- 0.80)
M7	10% Surface Area Island	2.70 (+/- 0.42)	0.67 (+/- 0.09)	30.33 (+/- 7.63)	8.33 (+/- 2.17)	91.66 (+/- 2.17)
M8	15% Surface Area Island	1.73 (+/- 0.38)	0.59 (+/- 0.04)	38.67 (+/- 5.60)	14.00 (+/- 0.00)	86.00 (+/- 0.00)
M9	Submerged Inlet	2.07 (+/- 0.16)	0.75 (+/- 0.01)	28.67 (+/- 2.88)	3.00 (+/- 0.00)	97.00 (+/- 0.00)
M10	Submerged Inlet (angled)	1.20 (+/- 0.28)	0.66 (+/- 0.07)	31.33 (+/- 7.63)	8.33 (+/- 2.17)	91.67 (+/- 2.17)
M11	Pond Base Flow	1.67 (+/- 0.21)	0.78 (+/- 0.05)	23.33 (+/-8.00)	3.00 (+/- 0.00)	97.00 (+/- 0.00)
Field Test 1/26/98		36	0.003	96.8	9.4	90.6

became divided with approximately 60-70% of the mass traveling towards the outlet, and the remaining 30-40% heading toward the far end away from the outlet. In essence, the inlet flow path divided the pond roughly in half creating two separate vortices. The mass heading towards the outlet initially skirted the perimeter of the pond but became divided from the bank prior to encountering the outlet. The outlet therefore was not in the main path of flow and only collected dye from the perimeter of the plume on this first pass. This path continued around and was eventually reintroduced to the inlet flow path. The flow path on the opposite side of the model also initially followed the perimeter but its' energy was more quickly dissipated by the larger volume and so was dispersed throughout the area. Dye was first detected at the outlet within two minutes of injection, and peak normalized concentrations were recorded within the first 7 minutes as the dye passed near the outlet. The average normalized peak concentration for the three runs was 1.9 with a maximum of 2.0 and a minimum of 1.7, as shown in Figure 10. Retention times obtained from the experiments were significantly lower than theoretical. The average normalized retention time was 0.63 with minimal variability based on an average mass recovery of 97%. Results of the Rebhum and Argaman analysis showed a relatively ineffective use of the pond volume, with dead space averaging 38%. CSTR type mixing was dominant, accounting for 97% of the effective volume.

3.5.2 Model Experiments with Base Flow Results

The base flow results echoed those of the original configuration with slight exceptions. The reduced flow rate produced a much greater residence time, approximately 78% of the theoretical and decreased dead space. Dead space decreased to an average of 20% of the pond volume. Apart from that, changes were minimal. Normalized peak concentrations obtained were similar, averaging 1.7. CSTR type mixing was essentially the same, accounting for 96% of the mixing within the effective volume. Base flow C(t) curves are shown in Figure 11.

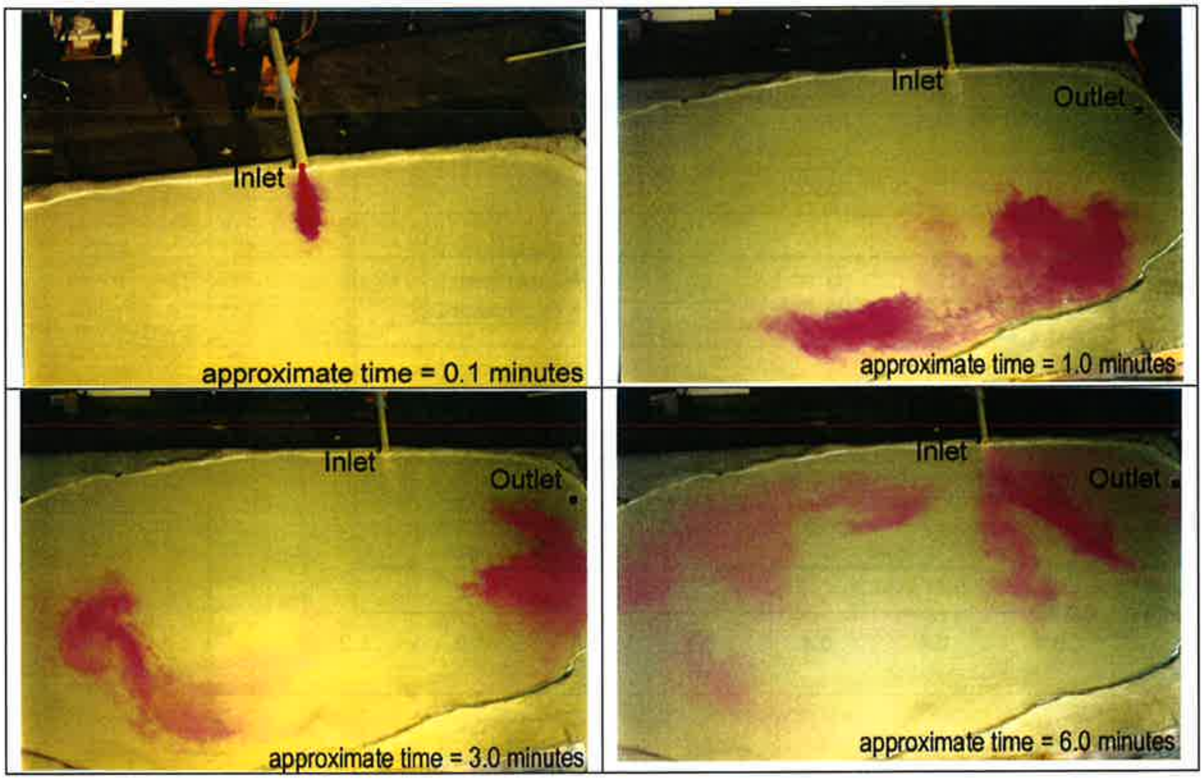


Figure 9. **Photographs of dye as a function of time for the scale model pond without modification.**

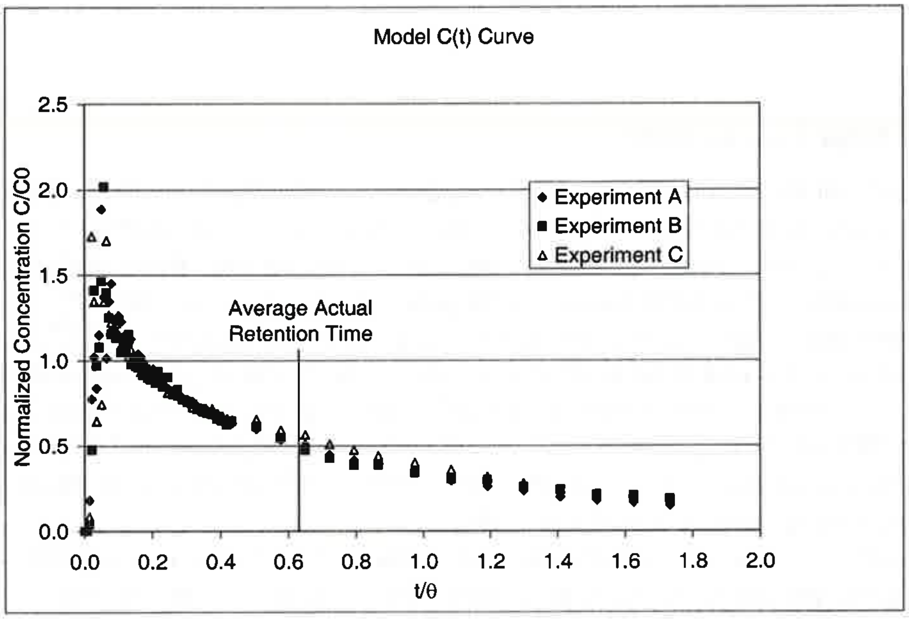


Figure 10. **C(t) curves from triplicate experiments for the model configuration without modification.**

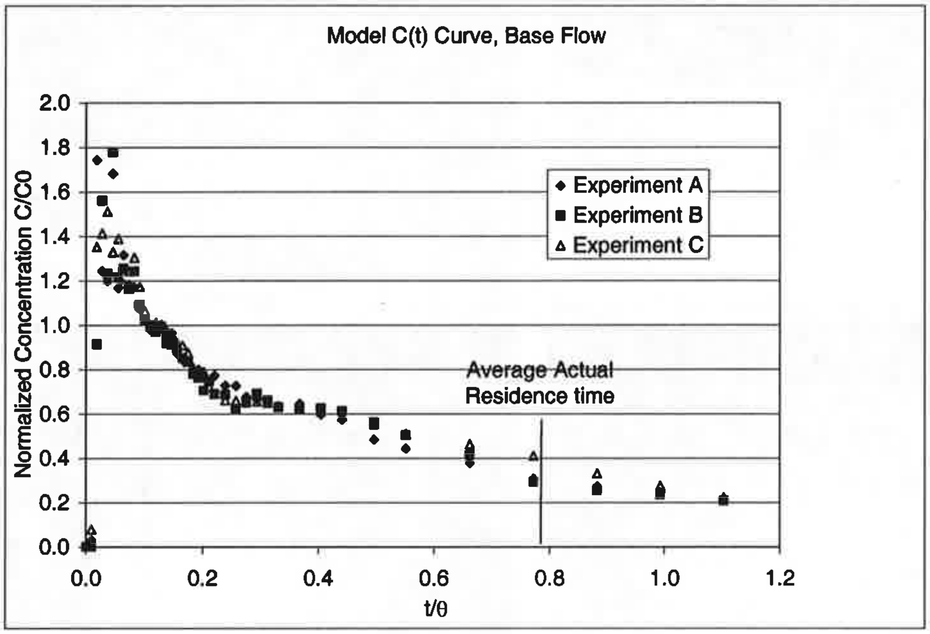


Figure 11. C(t) curves from triplicate experiments for the model configuration without inflow modification and flow scaled to the Spokane Pond Base Flow.

3.5.3 Field Tracer Test Results

The results of the two field tracer tests conducted on the Spokane Pond differ considerably (Figure 12). During both of the tests the water level was slightly lower than the top of the outlet grate. Outlet flows were generated from seepage through the outlet structure. In both tests, upon introduction to the pond, the dye was immediately split by the inlet sediment berm into two or more smaller plumes. In the January 25-26th test, dye was detected at the outlet within an hour of injection. A normalized peak concentration (C/C_0) of 36 was recorded at the end of the second hour. The test was concluded after 21 hours with just 20% of the dye mass recovered. Results of the Rebhum and Argaman analysis revealed a dead space of 97% of the pond volume. CSTR mixing accounted for the mixing in 90% of the effective volume (Table 11).

The second test was unsuccessful, as a peak dye concentration was not detected during the sampling period. It was later determined that a change in the inlet berm shape caused the dye to be directed away from the pond outlet and it is likely that the peak concentration arrived after sample collection ceased. The result of the second test was instructive however, in that it highlighted the importance of minor changes in inlet configuration and their impact of pond hydraulic characteristics.

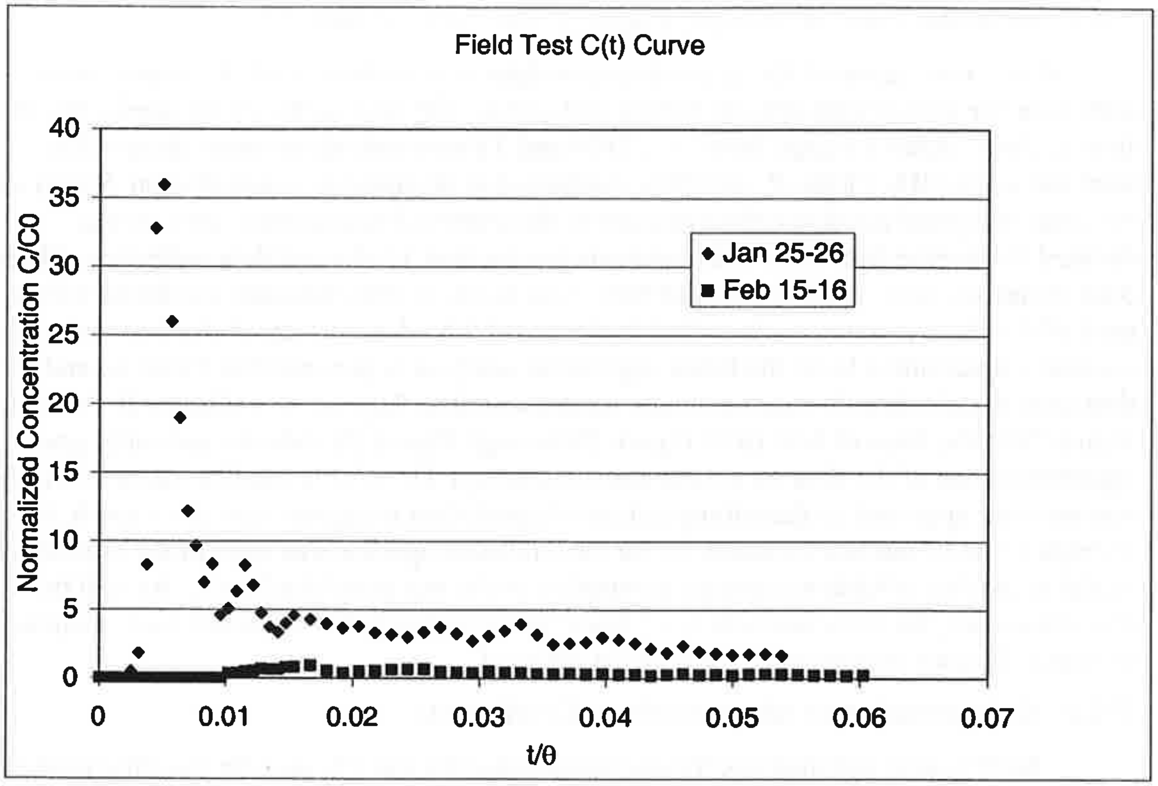


Figure 12. C(t) curves collected in the field at the Spokane pond.

3.6 Development of Numerical Model Parameters

3.6.1 Determination of Nutrient Degradation Rate Constants

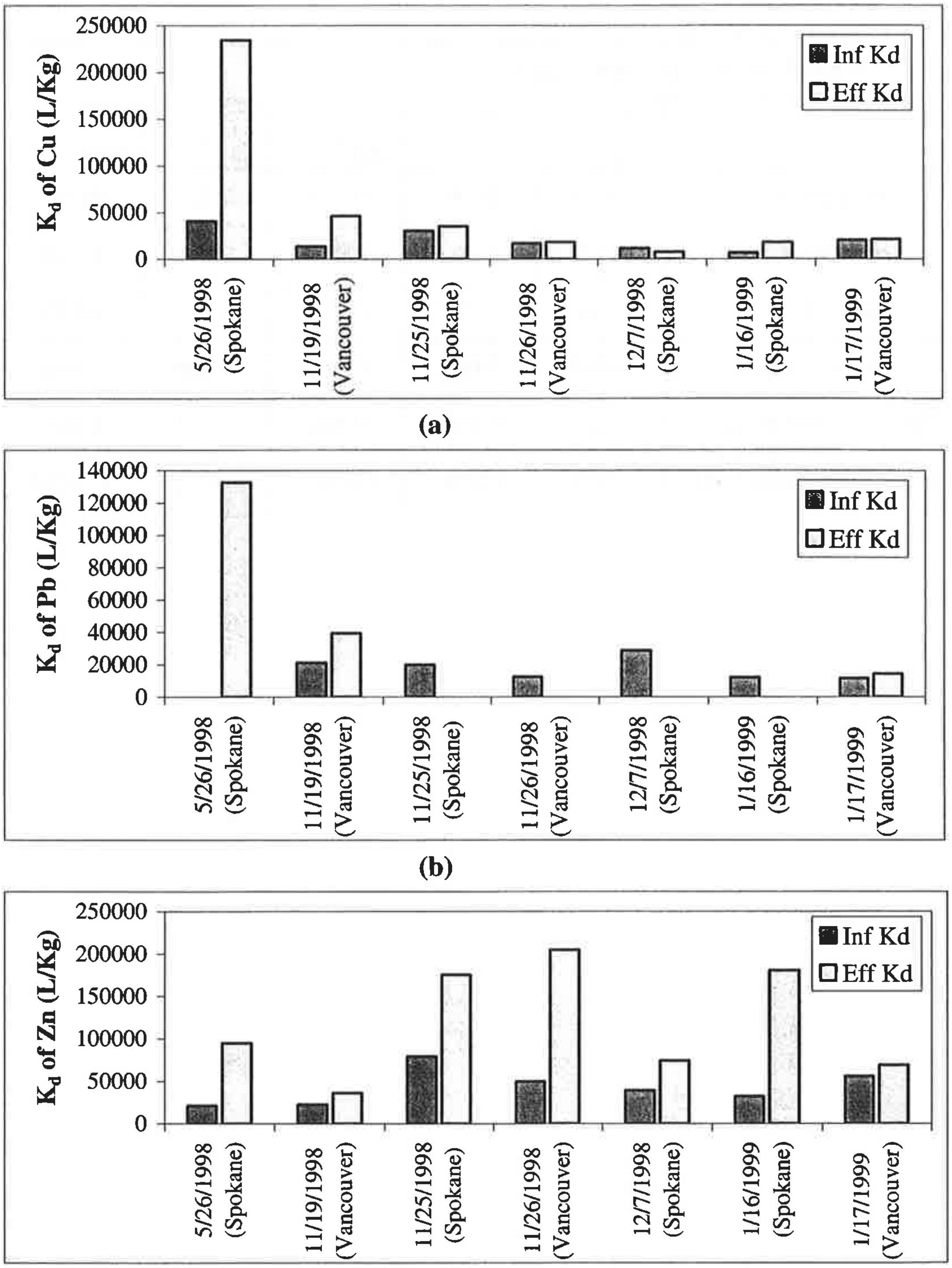
Upon assessment of the in-pond reactor data, it was observed that concentration reduction for all nutrients species (TKN, NH_3, NO_3^-, TP, and Ortho-P) occurred over the first 15 days. After 15 days, however, TKN and TP concentrations were observed to increase while NH_3, Ortho-P, and NO_3^- continued to decrease in concentration. Based on the short wet pond residence time relative to the observed degradation rates, it was decided to develop first order rate constants for the first 15 days of data collection. These data, therefore, were used to estimate first order reaction rate constants exhibited within each of the three reactors as described in Section 2.7.5. A summary of the first order rate constants determined from the linear regression analysis is presented in Table 12 and the data used to calculate the rate constants are presented in Appendix A (Figure 26 through Figure 28). The lines of best fit in Figure 26 through Figure 28 indicate generally good approximations of the data for all the nutrients except TKN. This implies that a first order reaction rate approach to describing nutrient degradation is appropriate. As a result, the average value of the rate constant, K, for each nutrient species was used in the numerical model to predict soluble nutrient concentration in the wet pond discharge. As will be discussed later, the rate constants were low relative to wet pond residence time, resulting in relatively poor performance for nutrient removal.

3.6.2 Determination of Metal Partition Coefficients

Storm event partition coefficient values (K_d) for Cu, Pb, and Zn resulting from the analytical method described in Section 2.7.4 are presented in Figure 13. The Student's t test was performed between average values of K_d for the Spokane pond inlet and outlet and the Vancouver pond inlet and outlet to determine whether there were statistically significant differences ($\alpha = 0.05$) (Table 13). As the statistical analysis data in Table 13 indicate, the average effluent K_d values are significantly greater than the influent values in both the Spokane and Vancouver ponds. This is likely a result of the general inverse relationship often observed between particle size and metal partitioning (67,68). Since smaller particles will be exiting the ponds, relative to the inlet particle size, one might expect a higher partition coefficient to be calculated when using the pond outlet data. In fact, this phenomenon was observed in our data as shown in Figure 14, data that is representative of both the Vancouver and Spokane ponds at all sample collection locations.

Table 12. Reaction rate constants for different nutrient species from three reactors in Spokane wet detention pond

	TKN day^{-1}	NH_3 day^{-1}	NO_3 day^{-1}	TP day^{-1}	OP day^{-1}
Reactor 1	0.013	0.048	0.054	0.136	0.107
Reactor 2	0.029	0.065	0.043	0.161	0.108
Reactor 3	0.0	0.042	0.053	0.111	0.055
Average	0.014	0.052	0.050	0.136	0.090
Standard deviation	0.014	0.012	0.006	0.025	0.030
Confidence interval (95%)	± 0.016	± 0.013	± 0.007	± 0.028	± 0.034



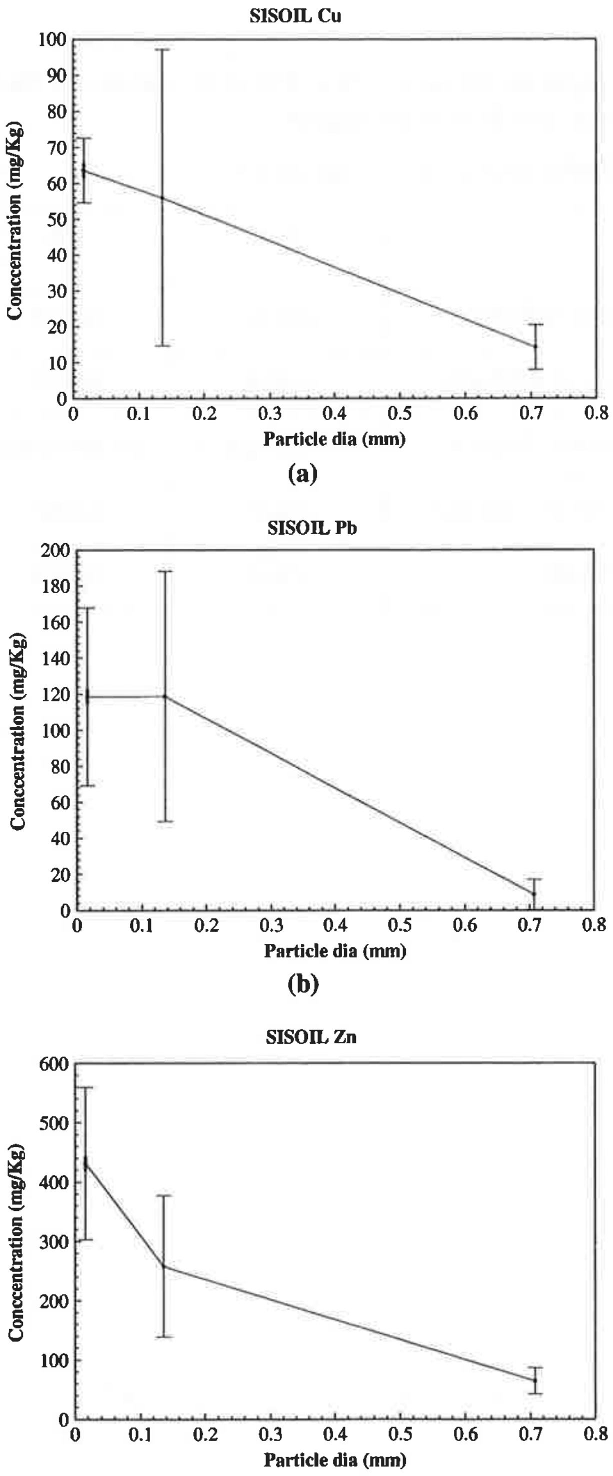
(c)

Figure 13. Event average partition coefficient (K_d) values of Cu, Pb, and Zn at the inlet (Inf) and outlet (Eff) of the Spokane and Vancouver ponds.

Table 13. Test of equality of means (t test) for K_d values at the Spokane and Vancouver wet detention ponds.

Null Hypothesis: Difference between means = 0

Samples	**Cu**	**Pb**	**Zn**
Spokane influent and effluent	reject	reject	reject
Vancouver influent and effluent	reject	reject	reject
Spokane and Vancouver influent	do not reject	do not reject	do not reject
Spokane and Vancouver effluent	reject	reject	do not reject
All influent and effluent	reject	reject	reject



(a)

(b)

(c)

Figure 14. Solid phase concentration of Cu, Pb and Zn as a function of soil particle size – sample collection location near the inlet of the Spokane wet detention pond. Confidence intervals ($\alpha = 0.05$) are based on triplicate analyses at each particle size.

The t test also indicated there is no statistically significant difference in the partition coefficient (K_d) values of Cu, Pb, and Zn between the influent of Spokane and Vancouver. However, there was statistical difference between the Spokane and Vancouver effluent K_d for Cu and Pb. The K_d value at Spokane was found to be higher than that of Vancouver, possibly a result of the presence of algae in the Spokane pond effluent, which can accumulate metals. Although this hypothesis cannot be confirmed, the data in Figure 15 indicated significantly higher average concentrations of chlorophyll in the Spokane pond effluent (106 mg/L) relative the average concentration in the Vancouver pond effluent (13 mg/L).

Table 14 provided a summary of average K_d values for Cu, Pb, Zn, and Cd with their maximum, minimum, standard deviation, and 95% confidence interval. These averages were used in the numerical model to calculate the efficiency of metal retention.

3.7 Numerical Model Evaluation

3.7.1 Flow Component

The flow component of the numerical model was first tested using a hypothetical rainfall event that generated a 1000 gpm inflow. The Spokane pond outflow from this test is shown in Figure 16. The pond was assumed to be full before the event and the rate of infiltration per unit pond surface area was taken to be 0.2 in/hr. The outflow hydrograph from this simulation (and others) is typical and indicated that the flow component of the numerical model was functioning properly.

The model output was then compared to field data for several storm events. A typical response is shown in Figure 17. The rising limb of the predicted outflow hydrograph yields a reasonably good representation of the field data. The falling limb, however, decreases at a lower rate in the prediction compared to the field data. This discrepancy is likely a result of variable infiltration rates that are known to exist in the pond. The Spokane pond has a partial clay liner that does not have the same elevation as the water level at full pool (it is at a lower level). Therefore, when the pond fills completely the infiltration rate is significantly greater due to the sandy soil in the area, causing a more rapid decrease in the measured outflow. The model, however, accommodates a single infiltration rate (0.2 in/hr for this simulation) that resulted in a smooth output curve.

3.7.2 Nutrient Removal Component

The numerical model nutrient removal evaluation was performed for NH_3 using the average first order rate constant of 0.05 day^{-1} (Table 12). Runoff from a one-hour storm was assumed that contained NH_3 at 1 mg/L and the initial NH_3 concentration in the pond was assumed to be zero. The predictive model indicated that 4 days were required to achieve a 50% reduction in pond effluent NH_3 concentration and it took more than 12 days to reduce the NH_3 concentration to near zero (Figure 18). When these data are compared to the average hydraulic detention time in the pond of less than a day for a 2 year, 24 hr event, it can be seen that nutrient reduction would not be expected under these conditions.

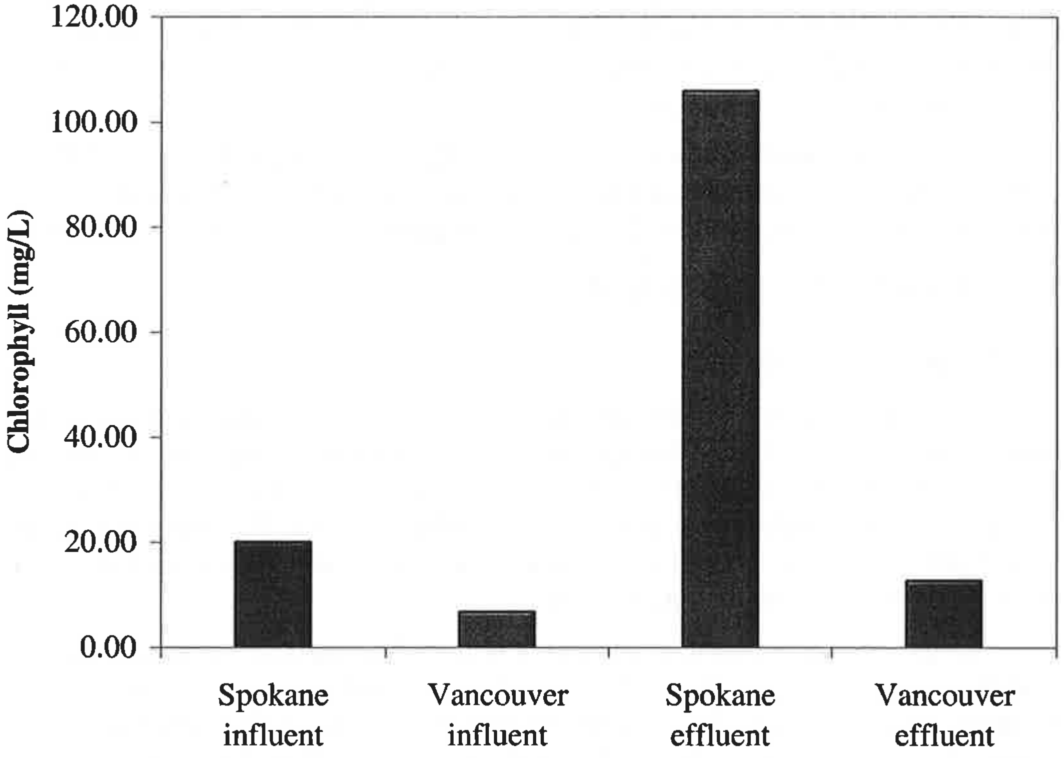


Figure 15. **Year averaged level of chlorophyll at inlet and outlet locations of the Spokane and Vancouver wet pond**

Table 14. Average and range of all partition coefficient data (K_d) for the inlet and outlet of both the Spokane and Vancouver ponds for Cu, Pb, and Zn.

Event mean K_d	Cu (L/kg)	Pb (L/kg)	Zn (L/kg)
Average	37097	32423	80917
Maximum	234257	132485	204577
Minimum	6437	11465	21164
Standard deviation	58002	38645	61497
Confidence interval (95%)	± 30382	± 25248	± 32213

3.7.3 Solids Removal Component

Removal of total suspended solids from the pond was calculated based on influent TSS concentration and their particle size distribution (PSD). Due to limited observation on PSD of influent TSS samples, a result of insufficient solids in the influent storm event samples to perform a sieve analysis, a defensible basis to determine the PSD of TSS was needed. Sediment samples were collected quarterly from three locations of the Spokane and Vancouver pond. The effluent and dead zone sample locations were in low velocity fields and exhibited a higher percentage of fines. These sample locations were, therefore, selected as being representative of pond influent TSS. The sieve size and percent finer data of the dead zone sediment samples of Spokane wet pond were analyzed and a mean particle size distribution curve was prepared (Figure 19). This PSD was used for evaluation of the TSS removal component of the numerical model.

A comparison of predicted and observed percent TSS removal four storm events at Spokane wet pond are shown in Figure 20. The predicted removal of TSS from the model is relatively close to the observed (maximum discrepancy is 16%). The model predicted higher removal in all cases, however.

A sensitivity analysis was performed to evaluate the influence of flow on percent TSS removal. The results indicate that, for the selected PSD, flow has a relatively small affect on removal (Figure 21). This result indicates the importance of PSD on pond performance. Specially, the removal is very sensitive to the smallest particles (those passing the No. 200 sieve). The data in Table 15 highlight this fact; it can be seen that even under a flow as high as 3000 gpm, the smallest particle that will be completely removed is 14.9 μm.

3.7.4 Metal Removal Component

As a result of the observed large range in values of K_d (Table 14) a sensitivity analysis was performed to evaluate the affect of K_d on predicted metal removals by varying K_d from 0 to 100,000 L/Kg. The results depicted in Figure 22 were encouraging when consideration is given to our measured range of K_d values. It can be seen that metal removal is significantly affected by K_d values up to approximately 5000 L/Kg. Removal is moderately sensitive between 5000 to 15000 L/Kg and beyond a partition coefficient of 15000 L/Kg, removal is essentially unaffected. Since the measured partition coefficients for this study were $\geq$ 32000 L/Kg, the selection of an average value for use in the model will be sufficient.

Comparisons of percent metal removal predictions to measured values are presented in Figure 23through Figure 25. The "K_d average" refers to the average partition coefficient of all the storm events as presented in Table 14. The flow, TSS, and metal concentration input were obtained from the data collected from the pond for each storm event. The predicted percent removals matched reasonably well with the observed data.

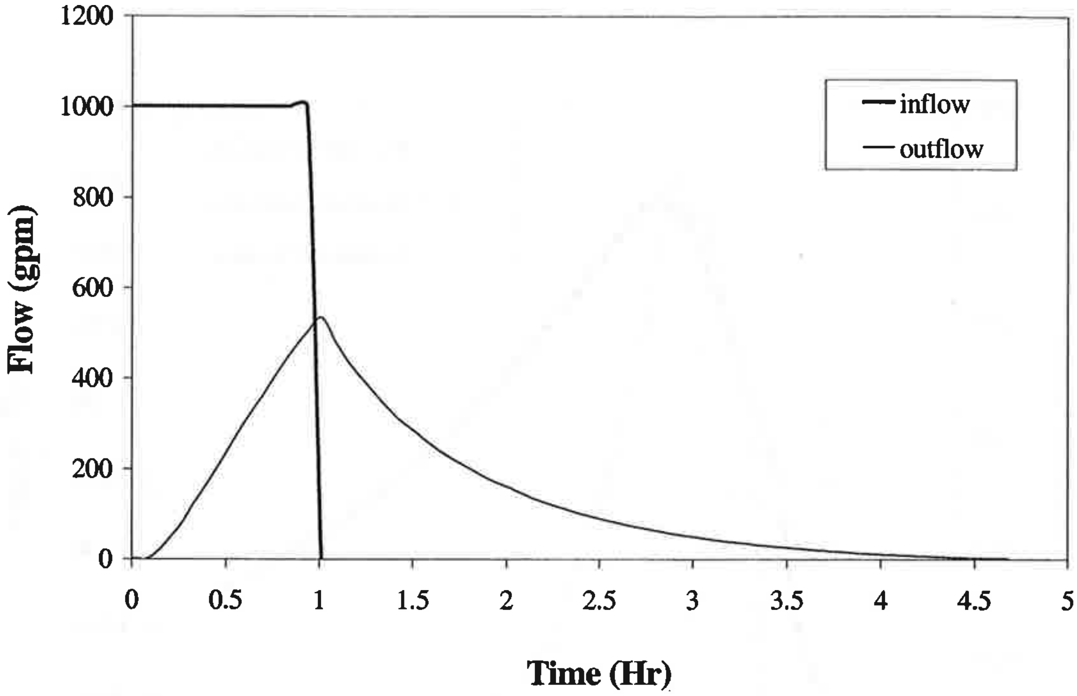


Figure 16. Spokane pond outflow resulting from a 1000 gpm inflow of one hour duration.

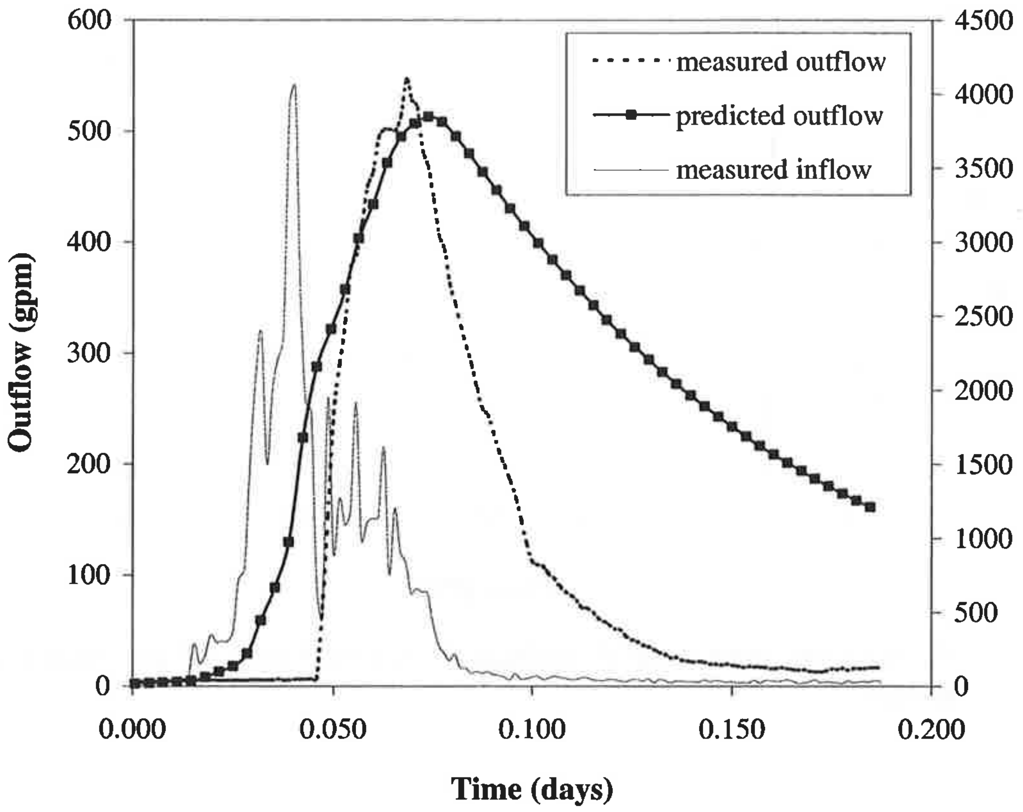


Figure 17. Model prediction compared to field data for the Spokane pond: storm event 5-13-98.

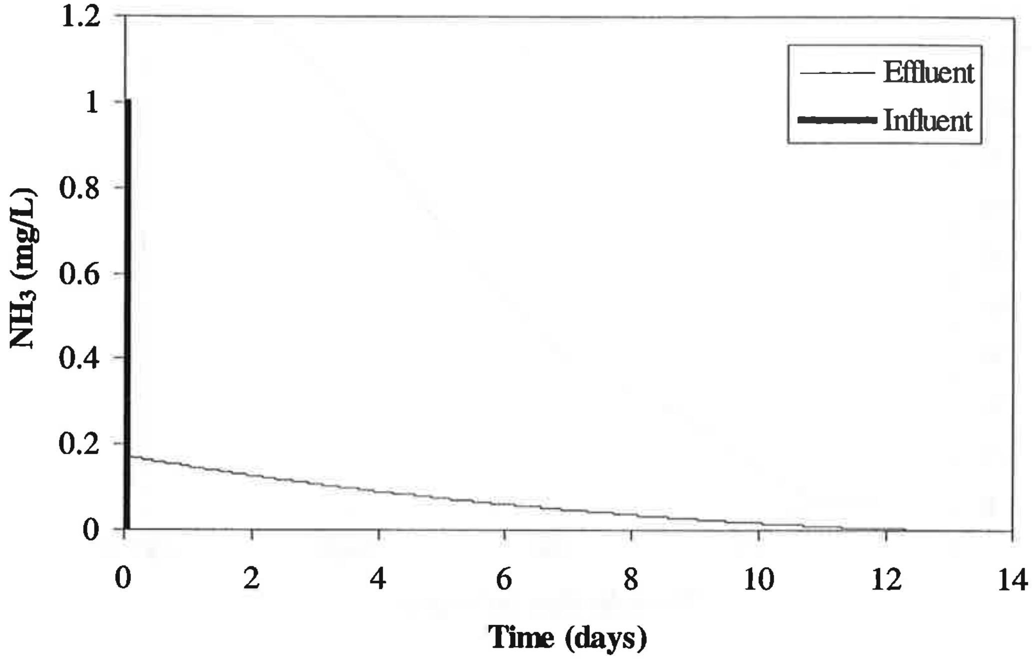


Figure 18. Model prediction of the Spokane pond effluent NH_3 concentration resulting from a one-hour runoff event containing 1 mg/L NH_3.

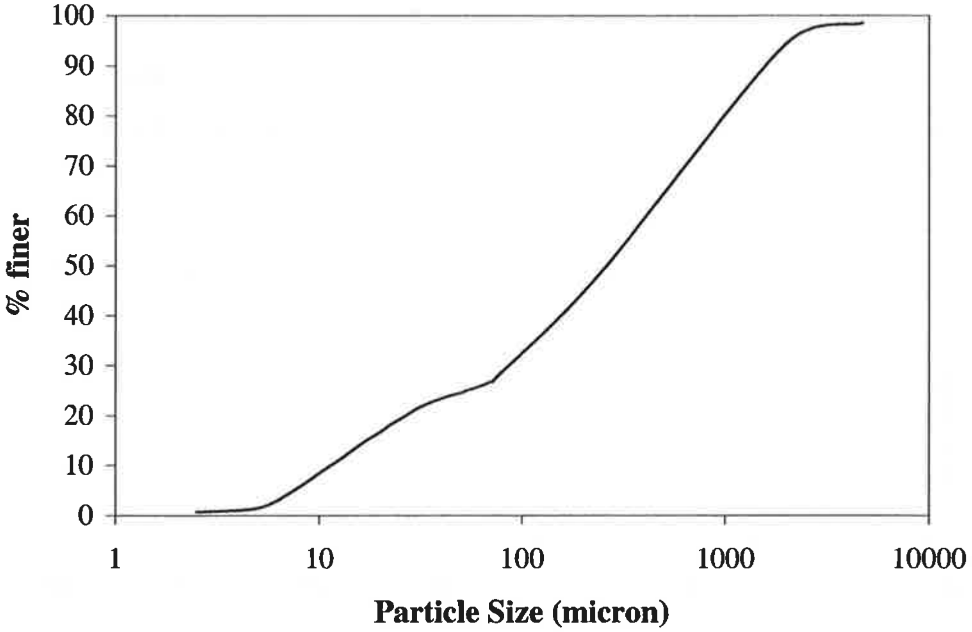


Figure 19. Particle size distribution of sediment collected from the dead zone sample collection location of the Spokane wet pond.

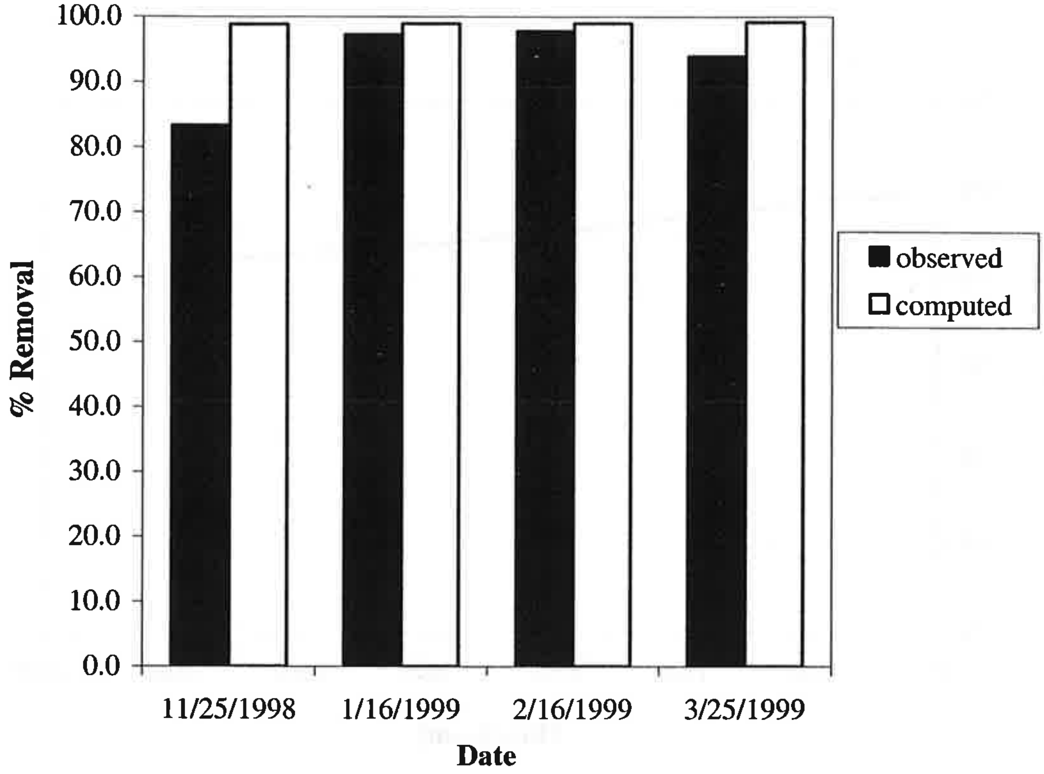


Figure 20. Comparison of observed and predicted TSS percent removal for four storm events at the Spokane wet pond

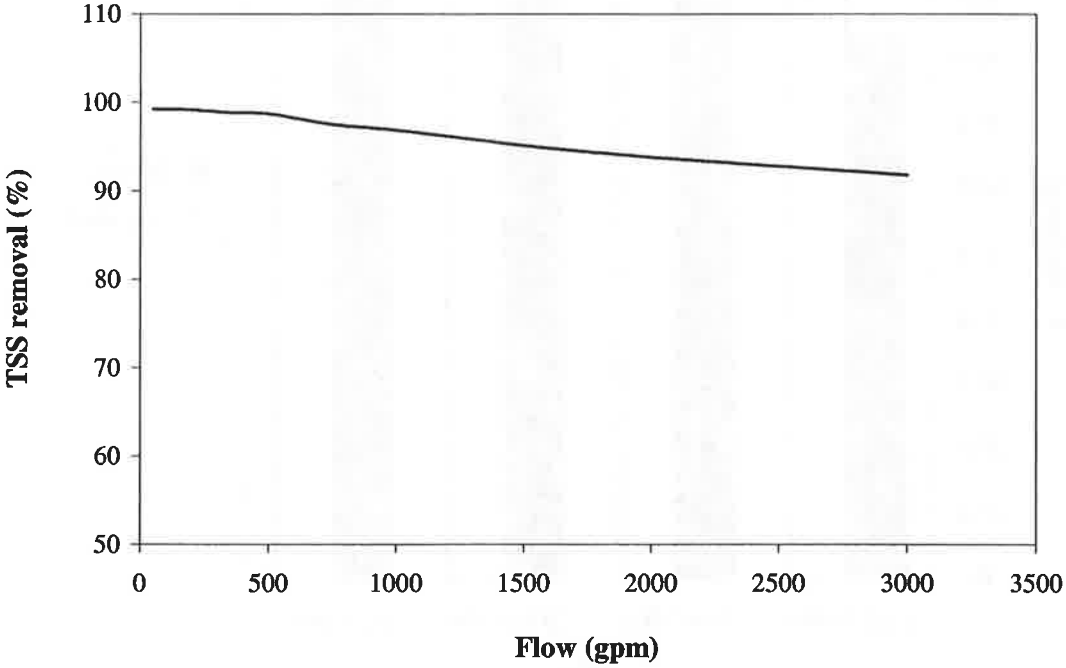


Figure 21. Sensitivity analysis of TSS percent removal as affected by flow.

Table 15. Percent removal and the smallest particle completely removed as a function of flow.

Flow (gpm)	TSS in (mg/L)	Predicted TSS out (mg/L)	Removal (%)	Smallest particle completely removed (µm)
50	500	3.71	99.26	1.9
100	500	3.71	99.26	2.7
200	500	4.06	99.19	3.8
350	500	5.71	98.86	5.1
500	500	6.36	98.73	6.1
750	500	12.29	97.54	7.5
1000	500	15.62	96.88	8.6
1500	500	24.29	95.14	10.5
2000	500	30.86	93.83	12.2
3000	500	40.97	91.81	14.9

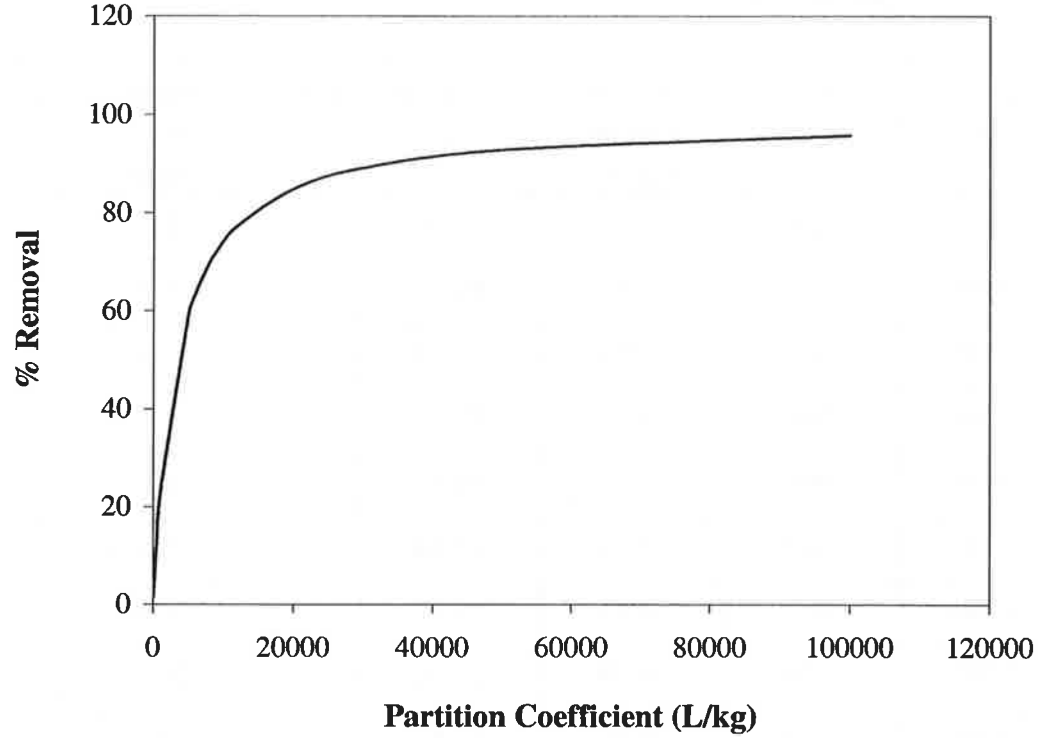


Figure 22. **Sensitivity analysis for percent metal removal as a function of K_d (Flow and TSS concentration were held constant)**

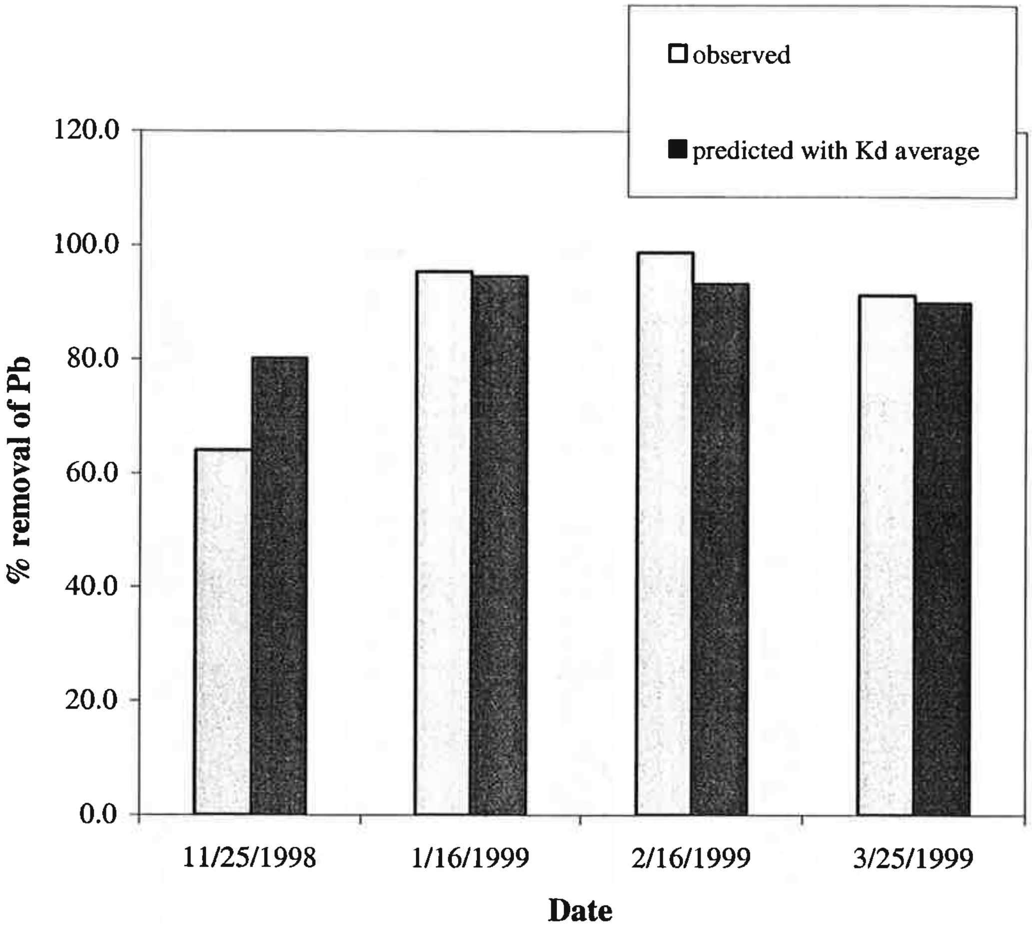


Figure 23. Comparison of predicted Pb removals, using a single average value of K_d, with observed removals for four storm events in the Spokane wet detention pond.

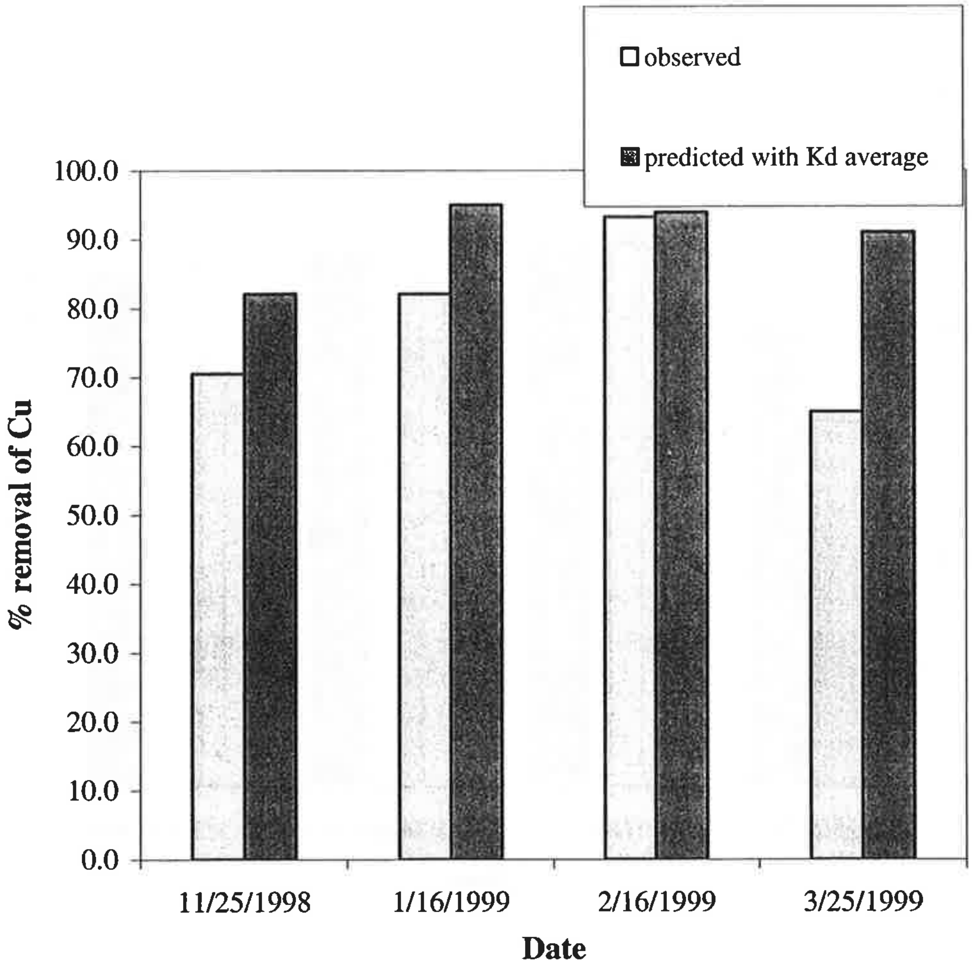


Figure 24. Comparison of predicted Cu removals, using a single average value of K_d, with observed removals for four storm events in the Spokane wet detention pond.

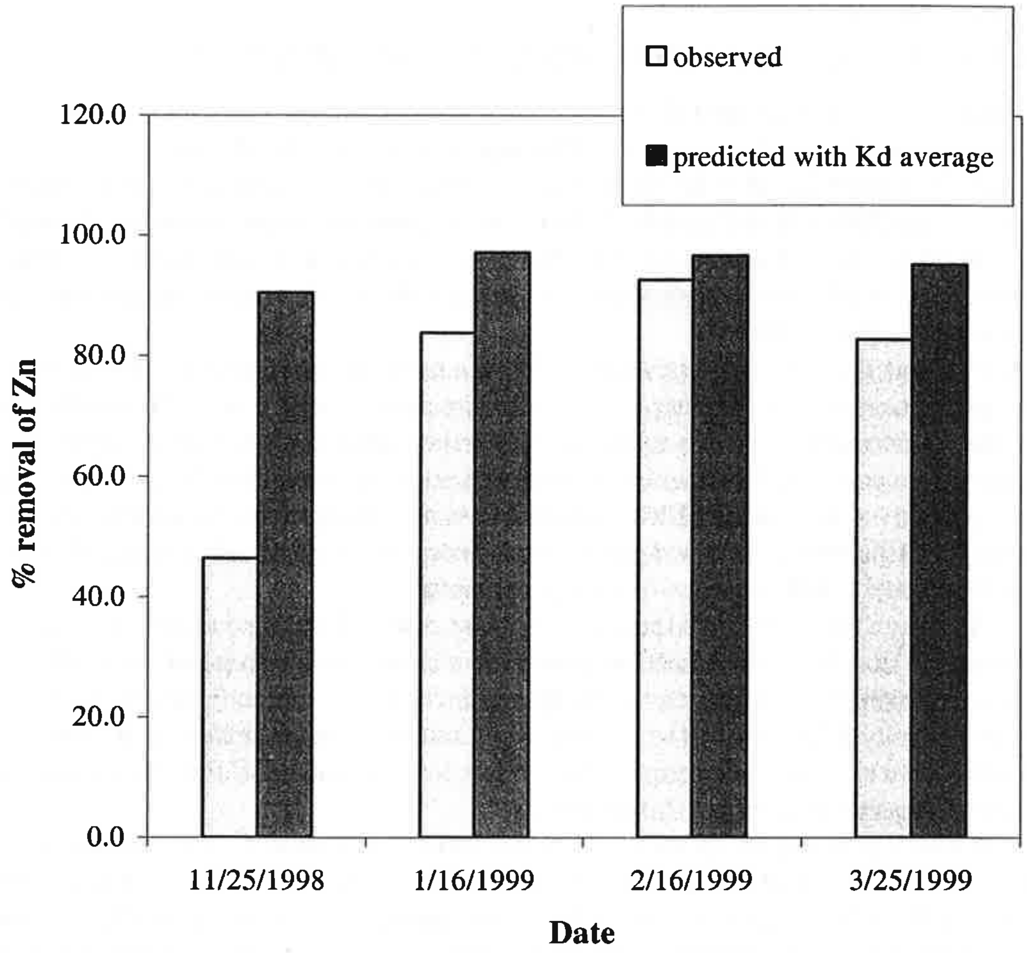


Figure 25. Comparison of predicted Zn removals, using a single average value of K_d, with observed removals for four storm events in the Spokane wet detention pond.

4 CHAPTER 4
CONCLUSIONS AND SUGGESTED RESEARCH

Pond influent and effluent discharges have been characterized with respect to several constituents found in highway runoff. TSS and total metal (Cu, Pb, and Zn) concentrations were found to be significantly reduced during each storm event in the Vancouver and Spokane wet ponds. Soluble metal concentrations, however, showed no general trend of concentration reduction from the pond influent to effluent. Effluent concentrations of all metals were found to be below the surface water quality standards for the state of Washington.

Nitrate was the only nutrient found to have a seasonal pattern in the Spokane pond discharge concentrations. Removal of nitrate was positive in the warmer months during algae growing seasons, and was negative during the colder months during algae senescence. In contrast, TKN and ammonia had positive removal efficiencies throughout the year, based on storm event EMC values. Average phosphorus concentration reduction for all storm events was poor with essentially no removal of ortho-phosphorus and approximately 30% removal of total phosphorous.

Although the EMC data indicated nutrient removal in some cases, in-pond reactor data indicated that first order reaction kinetics are slow relative to pond hydraulic detention time during storm events. The appearance of EMC concentration reduction could be a result of dilution of the pond influent nutrient concentration as it enters the wet pond when water column concentrations are less than the influent. Further evaluation would be necessary to confirm this hypothesis.

Rainfall patterns in Spokane and Vancouver had an effect on the presence or absence of a first flush of pollutants into the pond. For the coastal northwest, the more typical first flush behavior was minimal to nonexistent because of the small, frequent rain pattern characteristics of marine influenced climates of the northwest. Mediterranean climates have the majority of precipitation during the winter months, and for the inland northwest, this precipitation comes in the form of snow. All of the winter storm events investigated, except for one, had the pattern of a first flush for total metals but no first flush was observed for soluble metals. For the three remaining seasons, the presence or absence of a first flush coexisted for total and soluble metals. When a first flush occurred, the metals exhibiting the greatest first flush phenomenon was in the order Pb>Zn>Cu>Cd.

Nutrients did not follow the same first flush pattern. Ammonia, TKN, and total phosphorus were the most likely nutrients to exhibit a first flush; ortho-phosphorus had a first flush in only 18% of events analyzed. When a first flush occurred, the nutrients exhibiting the greatest first flush phenomenon was in the order TKN>ammonia>total phosphorus>nitrate>ortho-phosphorus.

PAH compounds were detected in stormwater runoff and in water column samples in both Vancouver and Spokane. The most prevalent were pyrene, fluoranthene, phenanthrene, and benzo(a)anthracene which are all reported to be emitted by automobiles. Although pond water column samples occasionally tested positive for PAH, all pond effluent samples tested were below the MDL for PAH.

Mildly toxic results were observed for 7 of 13 storm event samples tested. Only one effluent sample (Vancouver pond) exhibited a toxicity and this sample was also the only one to exhibit acute toxicity. No determination was made regarding the cause of toxicity however, and this would be a potential area of future research.

Scale model tracer testing indicated that wet ponds behave primarily as a CSTR with significant dead volume. This, and other factors, directed the numerical modeling toward a relatively straightforward 1-D predictive code. The code, imbedded within a decision support system, yields reasonably accurate predictions of TSS and metal removal and affords the user a means of generating wet pond outflow hydrographs.

The results of this research show that wet ponds are effective at removing many of the commonly found pollutants in highway runoff. Simple wet detention ponds, however, may not be sufficient for treating dissolved highway runoff constituents, the fraction that the USEPA has recommended to set and measure compliance with water quality standards.

4.1 Future Research

The Spokane pond scale model testing indicated that the addition of inlet baffles and/or islands can enhance hydraulic performance by reducing dead volume and decreasing peak discharge concentration. Currently, the design of a baffle or island would be based on specific field conditions and a good understanding of the impact of flow character on contaminant fate within a wet pond. Future research may focus on developing a set of nomographs for a range of pond shape and size so that "optimum" design could be more easily determined.

An expanded study on toxicity effects in receiving water would be warranted. The concentrations of constituents of concern in highway runoff are generally quite low, often near the limit of detection. In order to more fully understand and define perceived negative impacts, a carefully planned "impact" study would be very beneficial.

4.2 Wet Pond Maintenance and Modification

The field data from the Spokane pond clearly indicated that frequent dredging would be required to maintain optimum contaminant retention within the pond. This is a result of traction sand and gravel that is added to the highway receiving runoff. A substantial berm built up during the winter months that directed influent water toward the outlet, minimizing the effectiveness of the pond. The pond should be dredged at least once per year and preferably twice if it is a heavy snowfall year. Although the Vancouver pond also had a sediment berm that increased in size over the two-year study period, dredging frequency may be as infrequent as once every three years. These data indicate that pond maintenance (dredging) is required for optimum retention effectiveness and that the frequency of dredging would be site specific. It should be noted that under most circumstances only the inlet sediment berm would have to be removed to return the pond to design condition. A sediment forebay, designed to capture the larger fraction of runoff sediment prior to the main wet pond, could be effectively used in areas of high sediment load (traction sand application) to minimize cost associated with dredging.

Results of scale model testing of the Spokane wet pond indicated that hydraulic efficiency could be improved by disrupting the inlet flow path and directing it away from the outlet. Tracer experiments showed that inlet baffles angled towards the dead zone (away from the outlet structure) increased the effective volumes and decreased normalized peak concentrations during testing. Long baffles, at too great an angle, however, had the propensity to create a narrow plume and did not improve the hydraulic performance of the pond. Baffles creating broader plumes, such as the 30° angled baffle and the short 60° angled baffle, are more likely to improve performance under a wider range of circumstances.

Conclusions based on the island studies conducted in the model show that islands could effectively promote enhanced performance in wet ponds. Displaced pond volume due to the islands did not account for higher normalized peaks as might have been suspected. The largest island, accounting for 15% of the surface area, and approximately 11% of the pond volume, actually had the lowest average normalized peak of the three sets of island experiments. This suggests that the angle at which the island deflects the inlet stream is of critical importance. Islands should placed in such a manner as to direct as much of the inlet stream as possible towards the dead zone(s) and/or away from the outlet, and at an abrupt enough angle so as to avoid creating a flow path that simply follows the perimeter of the island.

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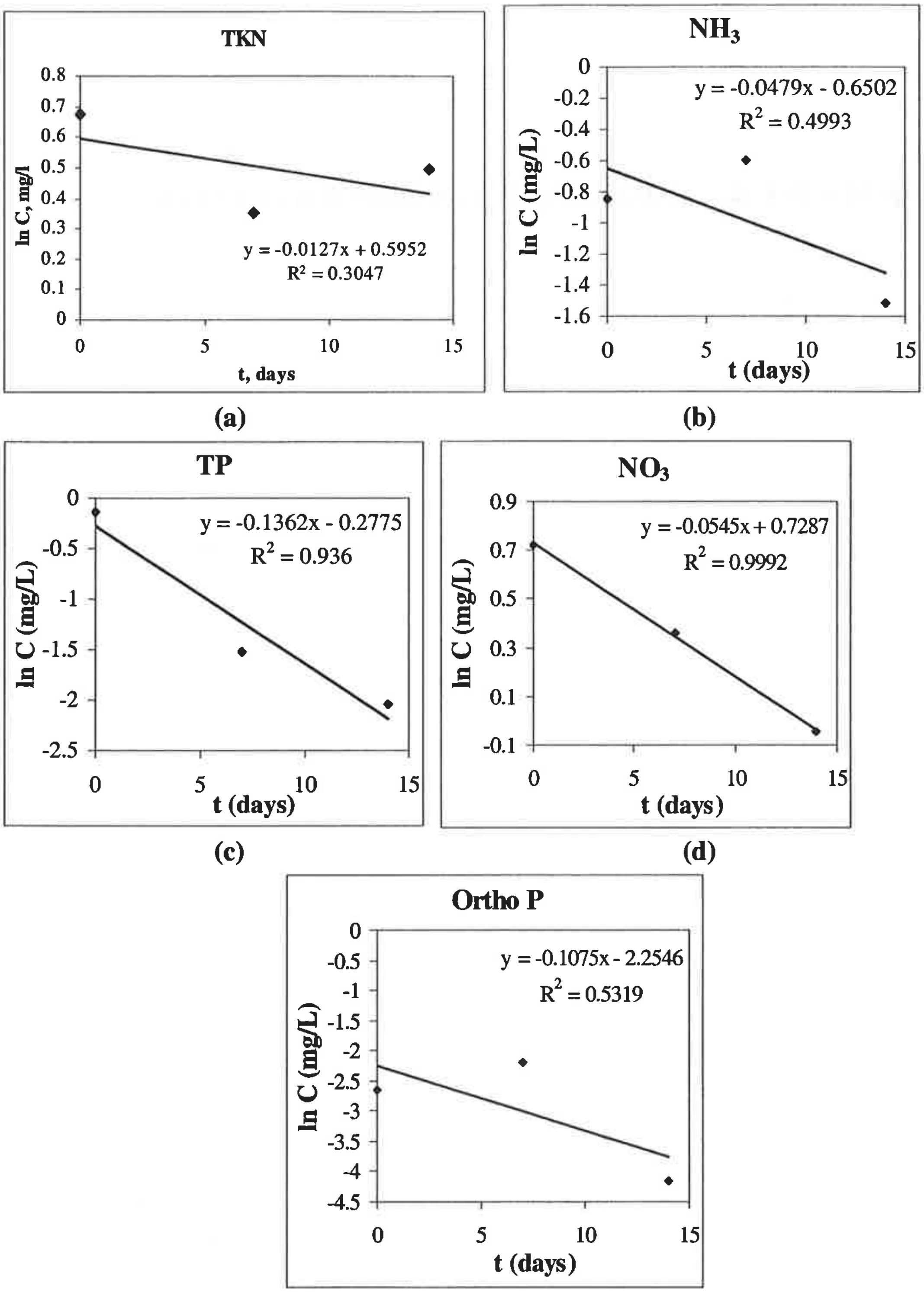
6 APPENDIX A – NUTRIENT REACTION RATE DATA

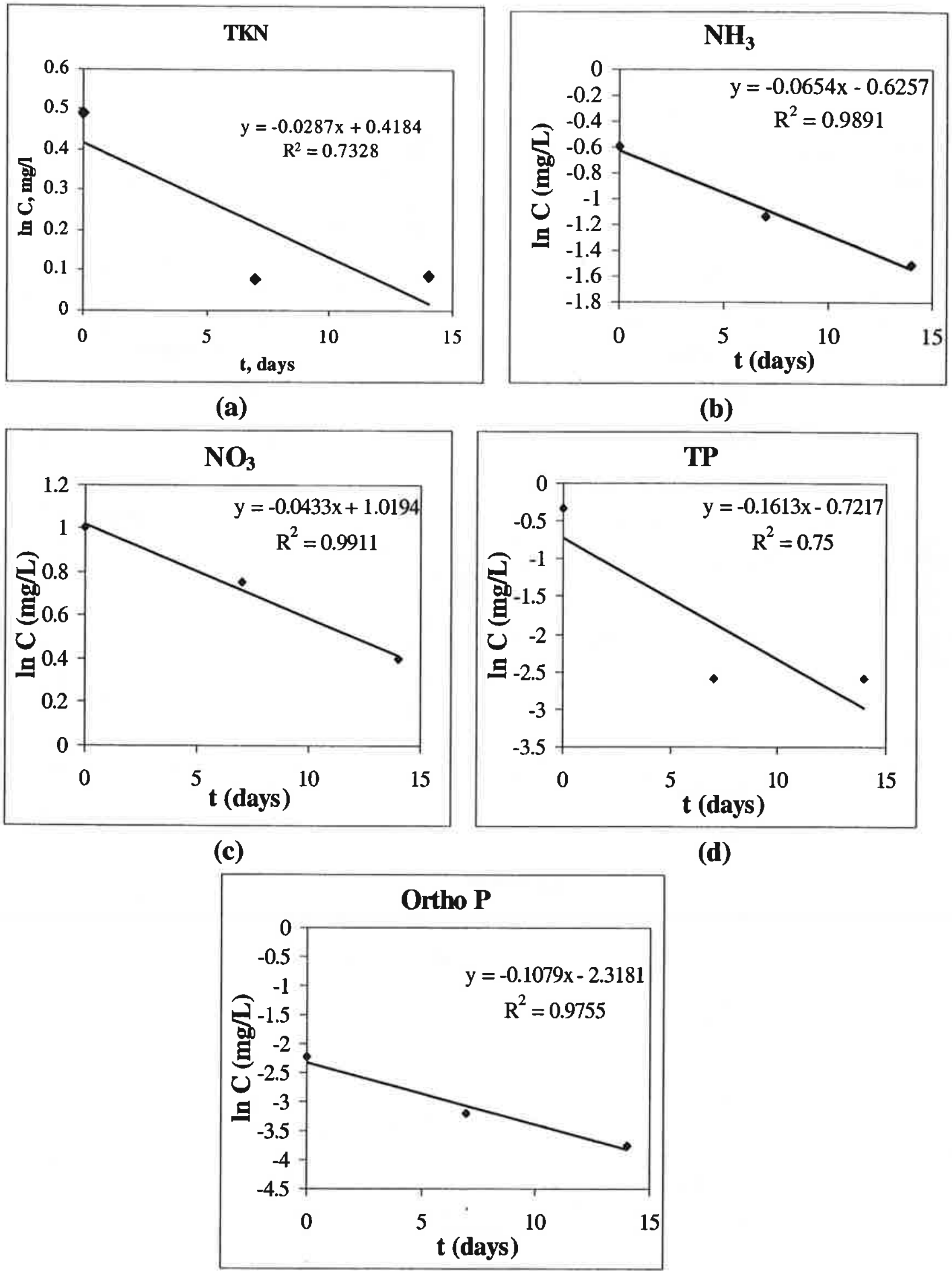


(a) **(b)**

(c) **(d)**

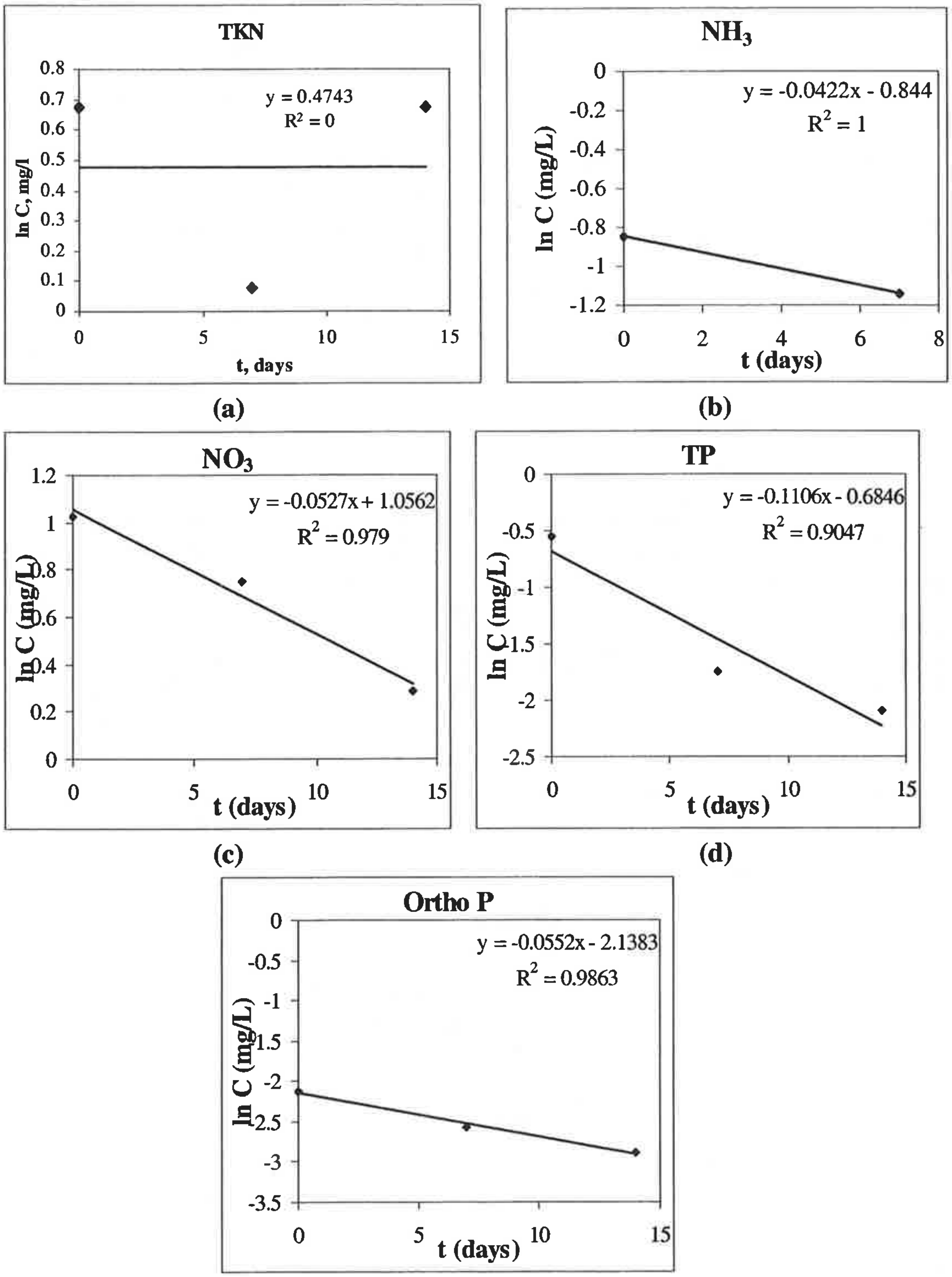
(e)

Figure 26. Data from reactor 1 of the Spokane wet detention pond that was used to calculate the first order reaction rate constants.



(a) **(b)** **(c)** **(d)** **(e)**

Figure 27. Data from reactor 2 of the Spokane wet detention pond that was used to calculate the first order reaction rate constants.



(a) (b)

(c) (d)

(e)

Figure 28. Data from reactor 3 of the Spokane wet detention pond that was used to calculate the first order reaction rate constants.

7 APPENDIX B – POND SEDIMENT DATA

Table 16. Pond sediment metal concentrations.

Sample Name Legend: V – Vancouver pond; S – Spokane pond; I – sample collected near the inlet structure; O – sample collected near the outlet structure; D – sample collected in the pond dead zone. Sample Position Legend: top – sediment sample from the top 3 cm of core; bottom – sediment sample from a depth of 3-6 cm.

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
VISOIL1	Vancouver	Influent		8/31/97	>60	262.62	107.15	89.55	nd
VISOIL2	Vancouver	Influent		8/31/97	>60	190.81	55.91	30.48	nd
VOSOIL3	Vancouver	Influent		8/31/97	>60	214.12	74.34	41.97	1.76
VESOIL	Vancouver	Effluent		8/31/97	>60	294.17	130.47	64.55	nd
VISOIL1	Vancouver	Influent		8/31/97	>200	276.95	338.02	182.29	nd
VISOIL2	Vancouver	Influent		8/31/97	>200	278.41	143.13	71.42	nd
VISOIL3	Vancouver	Influent		8/31/97	>200	243.94	110.63	66.80	nd
VESOIL	Vancouver	Effluent		8/31/97	>200	320.99	175.49	64.04	nd
VISOIL1	Vancouver	Influent		8/31/97	<200	540.92	303.30	214.45	nd
VISOIL2	Vancouver	Influent		8/31/97	<200	635.83	256.87	156.39	nd
VISOIL2	Vancouver	Influent		8/31/97	<200	550.47	238.58	126.95	nd
VESOIL	Vancouver	Effluent		8/31/97	<200	435.81	246.58	89.82	nd
SISOIL1	Spokane	Influent		1/31/98	>60	50.21	16.36	17.06	3.71
SISOIL2	Spokane	Influent		1/31/98	>60	74.51	16.66	24.79	1.07
SDSOIL	Spokane	Dead zone		1/31/98	>60	117.59	33.54	20.31	nd
SISOIL1	Spokane	Influent		1/31/98	>200	162.35	38.28	28.03	nd
SISOIL2	Spokane	Influent		1/31/98	>200	186.22	56.28	34.77	nd
SDSOIL	Spokane	Dead zone		1/31/98	>200	230.04	53.76	36.91	nd
SESOIL	Spokane	Effluent		1/31/98	>200	341.08	80.41	51.04	nd
SISOIL1	Spokane	Influent		1/31/98	<200	285.02	66.05	62.31	0.84
SISOIL2	Spokane	Influent		1/31/98	<200	288.43	70.27	58.26	nd
SDSOIL	Spokane	Dead zone		1/31/98	<200	267.53	78.49	44.61	nd
SESOIL	Spokane	Effluent		1/31/98	<200	399.69	81.45	48.38	nd

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
VISOILT	Vancouver	Influent	top	9/26/98	>60	195.46	104.64	53.28	nd
VISOILB	Vancouver	Influent	bottom	9/26/98	>60	231.88	119.81	49.32	nd
VDSOILT	Vancouver	Dead zone	top	9/26/98	>60	242.31	73.42	43.65	nd
VDSOILB	Vancouver	Dead zone	bottom	9/26/98	>60	284.21	128.76	48.27	nd
VESOILT1	Vancouver	Effluent	top	9/28/98	>60	703.57	239.39	110.90	nd
VESOILT2	Vancouver	Effluent	top	9/28/98	>60	708.10	252.94	119.20	nd
VESOILB1	Vancouver	Effluent	bottom	9/28/98	>60	366.07	253.81	63.46	nd
VESOILB2	Vancouver	Effluent	bottom	9/28/98	>60	501.37	309.96	105.37	nd
VISOILT	Vancouver	Influent	top	9/26/98	>200	253.09	104.73	77.81	nd
VISOILB	Vancouver	Influent	bottom	9/26/98	>200	308.77	156.22	76.38	nd
VDSOILT	Vancouver	Dead zone	top	9/26/98	>200	329.42	112.01	66.30	nd
VDSOILB	Vancouver	Dead zone	bottom	9/26/98	>200	309.48	90.03	41.67	nd
VESOILT1	Vancouver	Effluent	top	9/28/98	>200	636.71	231.38	115.87	nd
VESOILT2	Vancouver	Effluent	top	9/28/98	>200	631.73	225.23	124.58	2.59
VESOILB1	Vancouver	Effluent	bottom	9/28/98	>200	401.77	297.44	82.28	nd
VESOILB2	Vancouver	Effluent	bottom	9/28/98	>200	499.28	309.00	118.30	0.38
VISOILT	Vancouver	Influent	top	9/26/98	<200	541.61	221.86	154.58	nd
VISOILB	Vancouver	Influent	bottom	9/26/98	<200	572.56	296.59	156.22	nd
VDSOILT	Vancouver	Dead zone	top	9/26/98	<200	391.70	150.67	85.27	nd
VDSOILB	Vancouver	Dead zone	bottom	9/26/98	<200	441.10	204.83	92.18	nd
VESOILT1	Vancouver	Effluent	top	9/28/98	<200	546.77	225.16	93.35	nd
VESOILT2	Vancouver	Effluent	top	9/28/98	<200	537.82	229.33	100.12	nd
VESOILT1	Vancouver	Effluent	bottom	9/28/98	<200	416.79	334.41	76.82	nd
VESOILB2	Vancouver	Effluent	bottom	9/28/98	<200	417.04	288.94	89.75	nd
SISOIL	Spokane	Influent		1/12/99	>60	87.99	nd	13.81	nd
SESOILT	Spokane	Effluent	top	1/12/99	>60	43.26	nd	11.30	nd
SESOILB	Spokane	Effluent	bottom	1/12/99	>60	59.94	nd	13.38	nd
SISOIL	Spokane	Influent		1/12/99	>200	394.53	185.61	103.73	nd
SESOILT	Spokane	Effluent	top	1/12/99	>200	86.27	4.76	19.76	nd
SESOILB	Spokane	Effluent	bottom	1/12/99	>200	69.96	1.51	18.76	nd

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
SISOIL	Spokane	Influent		1/12/99	<200	530.88	121.73	73.95	nd
SESOILT	Spokane	Effluent	top	1/12/99	<200	125.57	20.65	36.83	nd
SESOILB	Spokane	Effluent	bottom	1/12/99	<200	76.71	9.36	22.53	nd
VISOIL	Vancouver	Influent		1/16/99	>60	200.94	45.29	31.52	nd
VISOILT	Vancouver	Influent	top	1/16/99	>60	189.77	66.79	37.63	nd
VISOILB	Vancouver	Influent	bottom	1/16/99	>60	241.25	72.99	47.25	nd
VDSOILT	Vancouver	Dead zone	top	1/16/99	>60	388.01	114.30	75.43	nd
VDSOILM	Vancouver	Dead zone	middle	1/16/99	>60	270.95	72.09	32.69	nd
VDSOILB	Vancouver	Dead zone	bottom	1/16/99	>60	278.46	98.77	45.34	nd
VESOILT	Vancouver	Effluent	top	1/16/99	>60	670.87	238.98	117.40	nd
VESOILB	Vancouver	Effluent	bottom	1/16/99	>60	330.73	322.93	68.33	nd
VISOIL	Vancouver	Influent		1/16/99	>200	182.05	65.63	36.87	nd
VISOILT	Vancouver	Influent	top	1/16/99	>200	218.95	110.76	59.44	nd
VISOILB	Vancouver	Influent	bottom	1/16/99	>200	244.37	116.49	45.90	nd
VDSOILT	Vancouver	Dead zone	top	1/16/99	>200	341.65	141.46	71.67	nd
VDSOILM	Vancouver	Dead zone	middle	1/16/99	>200	235.41	136.30	46.08	nd
VDSOILB	Vancouver	Dead zone	bottom	1/16/99	>200	310.97	178.94	52.02	nd
VESOILT	Vancouver	Effluent	top	1/16/99	>200	655.43	237.70	134.52	0.55
VESOILB	Vancouver	Effluent	bottom	1/16/99	>200	370.56	338.63	90.56	nd
VISOIL	Vancouver	Influent		1/16/99	<200	361.32	100.35	81.61	nd
VISOILT	Vancouver	Influent	top	1/16/99	<200	432.10	166.49	120.38	nd
VISOILB	Vancouver	Influent	bottom	1/16/99	<200	504.42	226.38	132.13	nd
VDSOILT	Vancouver	Dead zone	top	1/16/99	<200	437.21	177.98	99.87	nd
VDSOILM	Vancouver	Dead zone	middle	1/16/99	<200	406.38	208.05	97.54	nd
VDSOILB	Vancouver	Dead zone	bottom	1/16/99	<200	505.06	218.44	101.03	nd
VESOILB	Vancouver	Effluent	bottom	1/16/99	<200	354.40	360.93	78.90	nd
VESOILT	Vancouver	Effluent	top	1/16/99	<200	554.38	228.40	98.93	nd
						Zn (mg/Kg)	Pb (mg/Kg)	Cu (mg/Kg)	Cd (mg/Kg)
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>60	30.06	8.03	7.25	0.11

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>60	31.71	6.37	8.30	0.09
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>60	38.26	8.37	10.98	0.13
SESOILB	Spokane	Effluent	bottom	9/18/1998	>60	47.07	9.96	10.18	0.15
SESOILB	Spokane	Effluent	bottom	9/18/1998	>60	28.88	10.66	7.87	0.05
SESOILB	Spokane	Effluent	bottom	9/18/1998	>60	38.41	7.95	9.68	0.11
SISOIL	Spokane	Influent		9/18/1998	>60	28.83	6.32	6.29	0.08
SISOIL	Spokane	Influent		9/18/1998	>60	52.23	12.50	9.40	0.13
SISOIL	Spokane	Influent		9/18/1998	>60	51.90	11.68	9.71	0.10
SESOILT	Spokane	Effluent	top	9/18/1998	>60	231.44	75.49	32.07	1.23
SESOILT	Spokane	Effluent	top	9/18/1998	>60	96.29	41.31	16.15	0.55
SESOILT	Spokane	Effluent	top	9/18/1998	>60	144.18	42.84	23.08	0.81
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>200	53.35	18.70	12.28	0.23
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>200	79.59	18.74	17.82	0.24
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	>200	58.46	22.56	13.64	0.19
SESOILB	Spokane	Effluent	bottom	9/18/1998	>200	81.30	24.84	16.89	0.27
SESOILB	Spokane	Effluent	bottom	9/18/1998	>200	59.45	15.82	13.73	0.18
SESOILB	Spokane	Effluent	bottom	9/18/1998	>200	77.25	18.29	18.04	0.22
SISOIL	Spokane	Influent		9/18/1998	>200	205.64	145.84	39.25	0.71
SISOIL	Spokane	Influent		9/18/1998	>200	186.21	126.82	27.34	0.52
SISOIL	Spokane	Influent		9/18/1998	>200	226.85	98.64	32.94	0.80
SESOILT	Spokane	Effluent	top	9/18/1998	>200	272.57	101.59	41.53	1.20
SESOILT	Spokane	Effluent	top	9/18/1998	>200	102.13	45.08	19.34	0.60
SESOILT	Spokane	Effluent	top	9/18/1998	>200	148.93	54.50	23.47	0.79
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	<200	80.47	37.83	20.57	0.45
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	<200	110.09	39.31	29.12	0.46
SDSOILB	Spokane	Dead zone	bottom	9/18/1998	<200	85.35	32.70	23.56	0.42
SESOILB	Spokane	Effluent	bottom	9/18/1998	<200	149.93	66.82	29.96	0.94
SESOILB	Spokane	Effluent	bottom	9/18/1998	<200	110.37	38.38	33.76	0.41
SISOIL	Spokane	Influent		9/18/1998	<200	477.53	166.49	56.94	1.42
SESOILT	Spokane	Effluent	top	9/18/1998	<200	281.21	117.90	36.80	1.46
SESOILT	Spokane	Effluent	top	9/18/1998	<200	161.22	77.20	30.21	0.99

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
SESOILT	Spokane	Effluent	top	9/18/1998	<200	193.23	78.35	31.71	1.03
						Zn (mg/Kg)	Pb (mg/Kg)	Cu (mg/Kg)	Cd (mg/Kg)
VESOIL	Vancouver	Effluent		5/16/1998	>60	428.20	239.86	74.92	3.57
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>60	136.42	57.83	22.30	0.58
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>60	550.07	221.69	81.12	4.53
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>60	396.87	164.38	35.73	1.68
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>60	400.30	161.35	75.38	2.81
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>60	200.72	136.71	39.19	1.33
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>60	362.23	303.50	89.74	4.60
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>60	187.63	245.17	28.09	0.71
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>60	141.43	32.49	23.10	0.43
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>60	111.29	156.24	24.80	0.71
VISOILT	Vancouver	Influent	top	5/16/1998	>60	244.65	30.43	37.05	0.69
VISOILT	Vancouver	Influent	top	5/16/1998	>60	301.60	100.54	39.47	0.97
VISOILB	Vancouver	Influent	bottom	5/16/1998	>60	277.88	97.85	63.78	1.41
VISOILB	Vancouver	Influent	bottom	5/16/1998	>60	286.28	72.92	51.94	0.78
VESOIL	Vancouver	Effluent		5/16/1998	>200	467.48	244.23	84.03	4.32
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>200	202.66	123.51	35.85	1.08
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>200	491.70	229.30	81.89	4.51
VDSOILT	Vancouver	Dead zone	top	5/16/1998	>200	204.92	157.50	52.12	1.22
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>200	379.36	173.96	81.50	2.32
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>200	316.41	175.06	64.34	2.47
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	>200	302.10	314.47	74.13	2.70
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>200	182.14	112.46	35.98	0.49
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>200	174.38	120.73	32.64	0.56
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	>200	235.96	231.99	48.25	1.59
VISOILT	Vancouver	Influent	top	5/16/1998	>200	184.22	39.20	32.92	0.54
VISOILT	Vancouver	Influent	top	5/16/1998	>200	188.00	72.12	37.46	0.70
VISOILB	Vancouver	Influent	bottom	5/16/1998	>200	266.17	122.69	70.65	0.73

Sample Name	Sample Location	Pond Location	Sample Position	Sample Date	Sieve Number	Zn (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
VISOILB	Vancouver	Influent	bottom	5/16/1998	>200	367.77	102.77	88.78	0.91
VESOIL	Vancouver	Effluent		5/16/1998	<200	409.45	196.78	72.29	2.52
VDSOILT	Vancouver	Dead zone	top	5/16/1998	<200	258.43	178.82	45.82	1.40
VDSOILT	Vancouver	Dead zone	top	5/16/1998	<200	373.80	238.48	68.09	2.74
VDSOILT	Vancouver	Dead zone	top	5/16/1998	<200	285.12	257.61	76.67	1.58
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	<200	365.75	179.07	82.60	1.75
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	<200	386.41	192.47	79.87	2.31
VDSOILB	Vancouver	Dead zone	bottom	5/16/1998	<200	265.67	309.73	57.52	1.53
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	<200	333.62	231.70	70.41	1.14
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	<200	381.80	203.18	77.02	1.28
VDSOILM	Vancouver	Dead zone	middle	5/16/1998	<200	334.44	264.43	70.80	1.48
VISOILT	Vancouver	Influent	top	5/16/1998	<200	437.03	154.07	101.53	2.58
VISOILB	Vancouver	Influent	bottom	5/16/1998	<200	590.71	208.40	147.09	2.56
VISOILB	Vancouver	Influent	bottom	5/16/1998	<200	639.99	184.54	146.59	1.83
VDSOIL	Vancouver	Dead zone		8/31/1997	>60	288.79	66.49	35.11	0.99
VDSOIL	Vancouver	Dead zone		8/31/1997	>200	223.51	101.86	43.00	0.78
SDEPO	Spokane	Depo Box		5-17		988.42	97.27	91.77	2.56
SDEPO	Spokane	Depo Box		12-97--4-1-98		1174.67	192.99	53.26	3.65

8 APPENDIX C – POND INFLUENT AND EFFLUENT METAL DATA

Table 17. Pond influent and effluent metal concentrations. Note that these sample concentrations were developed on the ICP/MS.

Sample Name Legend: V – Vancouver pond; S – Spokane pond; I –stormwater inlet sample; E –stormwater pond outlet sample; COM# – refers to the sample number within a storm event, 1 is the first sample collected during the event, 2 is the second sample collected during the same event, etc.

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (μg/L)	Pb (μg/L)	Zn (μg/L)	Cd (μg/L)
SICOM1	Spokane	Influent	Storm Event	5/26/1998	Soluble	9.58	nd	79.79	nd
SICOM2	Spokane	Influent	Storm Event	5/26/1998	Soluble	12.64	nd	128.79	0.15
SICOM3	Spokane	Influent	Storm Event	5/26/1998	Soluble	12.88	nd	114.89	0.08
SICOM4	Spokane	Influent	Storm Event	5/26/1998	Soluble	10.37	nd	90.65	0.55
SICOM5	Spokane	Influent	Storm Event	5/26/1998	Soluble	16.60	nd	114.09	0.17
SICOM6	Spokane	Influent	Storm Event	5/26/1998	Soluble	20.15	nd	120.49	0.10
SICOM7	Spokane	Influent	Storm Event	5/26/1998	Soluble	7.93	nd	70.90	nd
SICOM8	Spokane	Influent	Storm Event	5/26/1998	Soluble	6.16	nd	52.70	nd
SECOM1	Spokane	Effluent	Storm Event	5/26/1998	Soluble	2.76	nd	151.49	nd
SECOM2	Spokane	Effluent	Storm Event	5/26/1998	Soluble	4.68	nd	38.49	nd
SECOM3	Spokane	Effluent	Storm Event	5/26/1998	Soluble	2.62	2.00	25.15	nd
SECOM4	Spokane	Effluent	Storm Event	5/26/1998	Soluble	2.64	5.26	59.96	nd
SECOM5	Spokane	Effluent	Storm Event	5/26/1998	Soluble	1.83	1.85	33.00	nd
SECOM6	Spokane	Effluent	Storm Event	5/26/1998	Soluble	1.49	1.80	29.09	nd
SECOM7	Spokane	Effluent	Storm Event	5/26/1998	Soluble	1.28	2.01	21.68	nd
SECOM8	Spokane	Effluent	Storm Event	5/26/1998	Soluble	2.84	2.48	22.99	nd
SICOM1	Spokane	Influent	Storm Event	5/26/1998	Total	30.56	26.58	186.95	1.43
SICOM2	Spokane	Influent	Storm Event	5/26/1998	Total	25.21	12.42	160.68	1.38
SICOM3	Spokane	Influent	Storm Event	5/26/1998	Total	23.04	14.00	141.23	1.32
SICOM4	Spokane	Influent	Storm Event	5/26/1998	Total	24.78	13.31	130.87	1.97
SICOM5	Spokane	Influent	Storm Event	5/26/1998	Total	23.38	12.88	128.07	1.17
SICOM6	Spokane	Influent	Storm Event	5/26/1998	Total	22.56	13.82	141.26	0.92
SICOM7	Spokane	Influent	Storm Event	5/26/1998	Total	20.42	12.03	135.20	0.75
SICOM8	Spokane	Influent	Storm Event	5/26/1998	Total	20.66	13.33	137.25	0.88
SECOM1	Spokane	Effluent	Storm Event	5/26/1998	Total	18.08	10.57	183.65	1.23
SECOM2	Spokane	Effluent	Storm Event	5/26/1998	Total	17.66	11.65	118.93	0.96
SECOM3	Spokane	Effluent	Storm Event	5/26/1998	Total	14.23	8.21	104.60	0.71

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SECOM4	Spokane	Effluent	Storm Event	5/26/1998	Total	18.83	12.78	130.28	1.39
SECOM5	Spokane	Effluent	Storm Event	5/26/1998	Total	22.03	17.01	169.11	1.03
SECOM6	Spokane	Effluent	Storm Event	5/26/1998	Total	24.51	13.41	140.48	0.77
SECOM7	Spokane	Effluent	Storm Event	5/26/1998	Total	18.90	13.74	135.27	0.85
SECOM8	Spokane	Effluent	Storm Event	5/26/1998	Total	23.31	15.84	147.91	1.02
SICOM1	Spokane	Influent	Storm Event	10/9/1998	Soluble	7.85	6.90	24.59	3.87
SICOM3	Spokane	Influent	Storm Event	10/9/1998	Soluble	11.56	6.91	140.89	3.99
SICOM4	Spokane	Influent	Storm Event	10/9/1998	Soluble	11.41	6.78	141.49	3.81
SICOM5	Spokane	Influent	Storm Event	10/9/1998	Soluble	12.05	6.89	100.49	3.86
SICOM6	Spokane	Influent	Storm Event	10/9/1998	Soluble	11.40	6.78	94.36	3.76
SICOM7	Spokane	Influent	Storm Event	10/9/1998	Soluble	11.04	6.88	100.39	4.02
SICOM8	Spokane	Influent	Storm Event	10/9/1998	Soluble	12.29	6.88	127.99	3.85
SECOM1	Spokane	Effluent	Storm Event	10/9/1998	Soluble	15.07	7.60	99.59	4.17
SECOM2	Spokane	Effluent	Storm Event	10/9/1998	Soluble	10.36	6.86	85.83	3.81
SECOM3	Spokane	Effluent	Storm Event	10/9/1998	Soluble	13.45	6.96	139.09	3.93
SECOM4	Spokane	Effluent	Storm Event	10/9/1998	Soluble	9.80	6.71	65.04	3.80
SECOM5	Spokane	Effluent	Storm Event	10/9/1998	Soluble	11.51	6.85	77.60	3.66
SECOM6	Spokane	Effluent	Storm Event	10/9/1998	Soluble	13.34	6.80	137.59	3.85
SECOM7	Spokane	Effluent	Storm Event	10/9/1998	Soluble	11.10	6.65	37.79	3.81
SECOM8	Spokane	Effluent	Storm Event	10/9/1998	Soluble	9.74	7.66	18.01	3.94
SICOM1	Spokane	Influent	Storm Event	10/9/1998	Total	156.48	277.93	1806.68	4.42
SICOM3	Spokane	Influent	Storm Event	10/9/1998	Total	33.09	21.29	370.57	1.59
SICOM4	Spokane	Influent	Storm Event	10/9/1998	Total	30.58	22.26	378.26	1.01
SICOM5	Spokane	Influent	Storm Event	10/9/1998	Total	26.76	14.92	302.30	0.76
SICOM7	Spokane	Influent	Storm Event	10/9/1998	Total	18.80	4.30	152.19	0.59
SICOM8	Spokane	Influent	Storm Event	10/9/1998	Total	20.41	5.08	176.23	0.53
SECOM1	Spokane	Effluent	Storm Event	10/9/1998	Total	308.77	528.45	2642.14	6.67
SECOM2	Spokane	Effluent	Storm Event	10/9/1998	Total	217.03	319.32	2203.34	5.06
SECOM3	Spokane	Effluent	Storm Event	10/9/1998	Total	130.60	158.73	1403.39	2.89
SECOM4	Spokane	Effluent	Storm Event	10/9/1998	Total	72.83	74.96	724.90	1.66
SECOM5	Spokane	Effluent	Storm Event	10/9/1998	Total	51.01	43.93	459.32	1.11
SECOM6	Spokane	Effluent	Storm Event	10/9/1998	Total	19.56	5.32	190.78	0.59
SECOM7	Spokane	Effluent	Storm Event	10/9/1998	Total	452.27	6.12	186.92	0.40
SECOM8	Spokane	Effluent	Storm Event	10/9/1998	Total	14.04	5.64	79.16	0.35

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SICOM1	Spokane	Influent	Storm Event	10/13/1998	Soluble	8.19	7.29	20.23	4.24
SICOM2	Spokane	Influent	Storm Event	10/13/1998	Soluble	6.46	7.29	17.54	3.90
SICOM3	Spokane	Influent	Storm Event	10/13/1998	Soluble	10.95	7.50	38.31	3.80
SICOM4	Spokane	Influent	Storm Event	10/13/1998	Soluble	12.95	7.51	54.76	3.86
SICOM5	Spokane	Influent	Storm Event	10/13/1998	Soluble	12.66	7.47	93.20	4.03
SICOM6	Spokane	Influent	Storm Event	10/13/1998	Soluble	16.90	7.41	70.97	4.00
SICOM7	Spokane	Influent	Storm Event	10/13/1998	Soluble	6.16	7.18	23.14	3.91
SECOM1	Spokane	Effluent	Storm Event	10/13/1998	Soluble	7.58	7.40	9.90	5.90
SECOM2	Spokane	Effluent	Storm Event	10/13/1998	Soluble	7.15	7.19	83.69	4.19
SECOM3	Spokane	Effluent	Storm Event	10/13/1998	Soluble	8.63	7.23	20.59	6.83
SECOM4	Spokane	Effluent	Storm Event	10/13/1998	Soluble	9.39	7.24	14.43	4.40
SECOM5	Spokane	Effluent	Storm Event	10/13/1998	Soluble	13.02	7.23	12.27	4.19
SECOM6	Spokane	Effluent	Storm Event	10/13/1998	Soluble	7.93	7.16	7.02	4.29
SECOM7	Spokane	Effluent	Storm Event	10/13/1998	Soluble	9.64	7.21	6.45	4.73
SECOM8	Spokane	Effluent	Storm Event	10/13/1998	Soluble	9.74	7.20	8.39	5.74
SICOM1	Spokane	Influent	Storm Event	10/13/1998	Total	29.68	18.69	273.22	0.96
SICOM2	Spokane	Influent	Storm Event	10/13/1998	Total	27.43	16.76	258.07	1.09
SICOM5	Spokane	Influent	Storm Event	10/13/1998	Total	11.46	6.25	87.63	0.43
SICOM7	Spokane	Influent	Storm Event	10/13/1998	Total	12.14	4.81	91.84	1.34
SICOM8	Spokane	Influent	Storm Event	10/13/1998	Total	10.03	3.57	73.75	0.61
SECOM2	Spokane	Effluent	Storm Event	10/13/1998	Total	7.35	1.20	43.11	0.77
SECOM3	Spokane	Effluent	Storm Event	10/13/1998	Total	9.22	1.54	48.21	4.05
SECOM4	Spokane	Effluent	Storm Event	10/13/1998	Total	10.25	1.84	76.95	1.30
SECOM5	Spokane	Effluent	Storm Event	10/13/1998	Total	20.89	2.12	64.52	1.19
SECOM7	Spokane	Effluent	Storm Event	10/13/1998	Total	14.90	1.27	24.60	1.55
VECOM1	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	8.24	7.61	67.82	4.60
VECOM2	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	9.14	7.75	73.54	4.35
VECOM3	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	9.46	7.75	73.78	4.45
VECOM4	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	9.31	7.81	76.63	4.53
VECOM5	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	9.13	7.74	82.58	4.45
VECOM6	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	8.72	7.68	69.68	4.32
VECOM7	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	9.46	8.18	75.79	4.36
VECOM8	Vancouver	Effluent	Storm Event	11/19/1998	Soluble	13.18	11.17	115.39	4.54
VICOM1	Vancouver	Influent	Storm Event	11/19/1998	Soluble	14.75	7.88	58.53	4.50

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
VICOM2	Vancouver	Influent	Storm Event	11/19/1998	Soluble	11.72	8.01	52.87	4.35
VICOM3	Vancouver	Influent	Storm Event	11/19/1998	Soluble	11.92	8.16	73.73	4.41
VICOM4	Vancouver	Influent	Storm Event	11/19/1998	Soluble	13.87	8.19	93.89	4.39
VICOM5	Vancouver	Influent	Storm Event	11/19/1998	Soluble	10.92	7.86	81.04	4.40
VICOM6	Vancouver	Influent	Storm Event	11/19/1998	Soluble	14.10	8.17	119.99	4.93
VICOM7	Vancouver	Influent	Storm Event	11/19/1998	Soluble	11.31	7.76	81.80	4.42
VICOM8	Vancouver	Influent	Storm Event	11/19/1998	Soluble	13.62	9.58	82.61	5.67
VICOM9	Vancouver	Influent	Storm Event	11/19/1998	Soluble	18.62	8.13	93.20	4.43
VICOM10	Vancouver	Influent	Storm Event	11/19/1998	Soluble	13.71	7.93	95.10	4.41
VICOM11	Vancouver	Influent	Storm Event	11/19/1998	Soluble	8.29	7.62	57.09	4.41
VICOM12	Vancouver	Influent	Storm Event	11/19/1998	Soluble	11.10	8.15	84.32	4.36
VICOM1	Vancouver	Influent	Storm Event	11/19/1998	Total	39.72	28.06	312.12	9.59
VICOM2	Vancouver	Influent	Storm Event	11/19/1998	Total	33.35	29.27	262.02	1.03
VICOM3	Vancouver	Influent	Storm Event	11/19/1998	Total	37.60	36.09	333.92	1.54
VICOM4	Vancouver	Influent	Storm Event	11/19/1998	Total	40.00	39.05	389.19	1.34
VICOM5	Vancouver	Influent	Storm Event	11/19/1998	Total	57.17	57.58	496.59	2.40
VICOM6	Vancouver	Influent	Storm Event	11/19/1998	Total	30.52	25.41	274.05	1.56
VICOM7	Vancouver	Influent	Storm Event	11/19/1998	Total	52.69	50.90	445.76	1.99
VICOM8	Vancouver	Influent	Storm Event	11/19/1998	Total	51.12	54.08	444.47	1.80
VICOM9	Vancouver	Influent	Storm Event	11/19/1998	Total	53.84	44.56	391.83	2.11
VICOM10	Vancouver	Influent	Storm Event	11/19/1998	Total	39.82	37.93	380.40	2.45
VICOM11	Vancouver	Influent	Storm Event	11/19/1998	Total	38.07	37.50	336.75	1.60
VICOM12	Vancouver	Influent	Storm Event	11/19/1998	Total	36.98	35.22	312.36	1.40
VECOM1	Vancouver	Effluent	Storm Event	11/19/1998	Total	23.06	18.17	190.12	1.23
VECOM2	Vancouver	Effluent	Storm Event	11/19/1998	Total	20.73	14.99	155.03	0.87
VECOM3	Vancouver	Effluent	Storm Event	11/19/1998	Total	20.52	15.51	137.82	0.72
VECOM4	Vancouver	Effluent	Storm Event	11/19/1998	Total	21.99	18.06	153.36	1.04
VECOM5	Vancouver	Effluent	Storm Event	11/19/1998	Total	20.42	16.17	140.38	0.83
VECOM6	Vancouver	Effluent	Storm Event	11/19/1998	Total	21.87	17.86	151.11	1.14
VECOM7	Vancouver	Effluent	Storm Event	11/19/1998	Total	23.69	19.82	165.32	1.28
VECOM8	Vancouver	Effluent	Storm Event	11/19/1998	Total	23.60	19.90	161.57	1.45
SICOM1	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.38	7.25	49.08	3.86

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SICOM2	Spokane	Influent	Storm Event	11/20/1998	Soluble	8.16	7.26	45.16	3.98
SICOM3	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.72	7.24	34.22	3.88
SICOM4	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.92	7.28	39.54	3.87
SICOM5	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.69	7.50	37.45	4.02
SICOM6	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.27	7.36	31.17	3.81
SICOM7	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.07	7.43	25.32	3.83
SICOM8	Spokane	Influent	Storm Event	11/20/1998	Soluble	7.89	7.41	56.67	3.94
SECOM1	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.78	7.22	1210.09	4.01
SECOM2	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.92	7.15	1172.09	3.91
SECOM3	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.41	7.13	1262.09	3.73
SECOM4	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.69	7.17	354.49	3.79
SECOM5	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.41	7.14	187.49	3.75
SECOM6	Spokane	Effluent	Storm Event	11/20/1998	Soluble	6.84	7.16	105.99	3.85
SECOM7	Spokane	Effluent	Storm Event	11/20/1998	Soluble	7.00	7.20	77.97	3.82
SECOM8	Spokane	Effluent	Storm Event	11/20/1998	Soluble	5.34	7.11	50.71	3.94
SICOM1	Spokane	Influent	Storm Event	11/20/1998	Total	49.41	45.98	537.30	2.54
SICOM3	Spokane	Influent	Storm Event	11/20/1998	Total	51.43	48.35	541.22	2.09
SICOM4	Spokane	Influent	Storm Event	11/20/1998	Total	56.87	53.94	540.63	2.17
SICOM5	Spokane	Influent	Storm Event	11/20/1998	Total	55.65	60.19	578.20	2.24
SICOM6	Spokane	Influent	Storm Event	11/20/1998	Total	61.91	82.45	584.70	2.66
SICOM8	Spokane	Influent	Storm Event	11/20/1998	Total	29.12	27.58	276.73	1.35
SECOM1	Spokane	Effluent	Storm Event	11/20/1998	Total	49.44	62.07	5235.99	1.81
SECOM2	Spokane	Effluent	Storm Event	11/20/1998	Total	58.52	74.82	10732.15	3.33
SECOM3	Spokane	Effluent	Storm Event	11/20/1998	Total	39.10	45.57	8608.61	1.38
SECOM4	Spokane	Effluent	Storm Event	11/20/1998	Total	18.86	15.59	1828.61	0.68
SECOM5	Spokane	Effluent	Storm Event	11/20/1998	Total	12.71	8.68	801.34	0.53
SECOM6	Spokane	Effluent	Storm Event	11/20/1998	Total	14.96	11.95	544.13	0.86
SECOM7	Spokane	Effluent	Storm Event	11/20/1998	Total	10.51	5.83	295.99	0.61
SECOM8	Spokane	Effluent	Storm Event	11/20/1998	Total	12.18	6.95	304.58	0.70
SICOM1	Spokane	Influent	Storm Event	11/25/1998	Soluble	8.87	7.30	25.49	3.81
SICOM2	Spokane	Influent	Storm Event	11/25/1998	Soluble	8.54	7.30	23.91	3.82
SICOM3	Spokane	Influent	Storm Event	11/25/1998	Soluble	8.39	7.30	30.11	3.84
SICOM4	Spokane	Influent	Storm Event	11/25/1998	Soluble	7.93	7.35	29.49	3.77
SICOM5	Spokane	Influent	Storm Event	11/25/1998	Soluble	7.94	7.34	24.31	3.76

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SICOM6	Spokane	Influent	Storm Event	11/25/1998	Soluble	7.93	7.35	21.15	3.80
SICOM7	Spokane	Influent	Storm Event	11/25/1998	Soluble	7.23	7.27	25.53	3.79
SICOM8	Spokane	Influent	Storm Event	11/25/1998	Soluble	6.41	7.35	100.89	3.84
SECOM1	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.15	7.23	57.68	4.20
SECOM2	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.15	7.21	47.81	4.25
SECOM3	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.42	7.23	60.69	4.22
SECOM4	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.15	7.21	34.86	4.26
SECOM5	Spokane	Effluent	Storm Event	11/25/1998	Soluble	6.56	7.13	25.85	4.21
SECOM6	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.48	7.23	36.20	4.15
SECOM7	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.06	7.17	30.46	4.17
SECOM8	Spokane	Effluent	Storm Event	11/25/1998	Soluble	7.00	7.19	30.33	4.23
SICOM1	Spokane	Influent	Storm Event	11/25/1998	Total	172.04	48.83	475.92	1.25
SICOM2	Spokane	Influent	Storm Event	11/25/1998	Total	37.40	30.47	354.19	1.06
SICOM3	Spokane	Influent	Storm Event	11/25/1998	Total	34.34	29.56	380.25	1.15
SICOM4	Spokane	Influent	Storm Event	11/25/1998	Total	31.82	28.66	328.92	1.08
SICOM5	Spokane	Influent	Storm Event	11/25/1998	Total	14.72	9.25	211.42	0.58
SICOM6	Spokane	Influent	Storm Event	11/25/1998	Total	26.53	23.24	341.01	1.19
SICOM7	Spokane	Influent	Storm Event	11/25/1998	Total	10.79	6.35	190.90	0.35
SICOM8	Spokane	Influent	Storm Event	11/25/1998	Total	27.19	20.77	253.45	0.71
SECOM1	Spokane	Effluent	Storm Event	11/25/1998	Total	7.87	3.03	147.77	0.40
SECOM2	Spokane	Effluent	Storm Event	11/25/1998	Total	18.83	4.14	157.41	4.10
SECOM3	Spokane	Effluent	Storm Event	11/25/1998	Total	11.94	7.07	196.60	0.49
SECOM4	Spokane	Effluent	Storm Event	11/25/1998	Total	10.85	7.08	173.12	0.42
SECOM5	Spokane	Effluent	Storm Event	11/25/1998	Total	8.14	6.69	148.13	0.40
SECOM6	Spokane	Effluent	Storm Event	11/25/1998	Total	8.46	6.07	131.65	0.28
SECOM7	Spokane	Effluent	Storm Event	11/25/1998	Total	30.47	34.72	295.43	3.28
SECOM8	Spokane	Effluent	Storm Event	11/25/1998	Total	7.75	3.51	109.21	0.34
VICOM1	Vancouver	Influent	Storm Event	11/26/1998	Soluble	7.96	7.22	50.49	4.27
VICOM2	Vancouver	Influent	Storm Event	11/26/1998	Soluble	7.09	7.32	48.14	4.24
VICOM3	Vancouver	Influent	Storm Event	11/26/1998	Soluble	5.34	7.15	33.44	4.19
VICOM4	Vancouver	Influent	Storm Event	11/26/1998	Soluble	6.34	7.23	43.05	4.29
VICOM5	Vancouver	Influent	Storm Event	11/26/1998	Soluble	7.92	7.29	38.07	4.21
VICOM6	Vancouver	Influent	Storm Event	11/26/1998	Soluble	5.95	7.28	27.03	4.13
VICOM7	Vancouver	Influent	Storm Event	11/26/1998	Soluble	5.69	7.25	32.04	4.23

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
VICOM8	Vancouver	Influent	Storm Event	11/26/1998	Soluble	5.88	7.80	27.40	4.26
VICOM9	Vancouver	Influent	Storm Event	11/26/1998	Soluble	5.18	7.20	25.00	4.24
VICOM10	Vancouver	Influent	Storm Event	11/26/1998	Soluble	6.48	7.41	28.55	4.13
VICOM11	Vancouver	Influent	Storm Event	11/26/1998	Soluble	6.24	7.37	37.66	4.15
VICOM12	Vancouver	Influent	Storm Event	11/26/1998	Soluble	6.21	7.41	28.52	4.12
VECOM1	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	7.37	8.39	49.73	5.22
VECOM2	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	6.65	7.94	37.87	4.71
VECOM3	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	5.99	7.42	36.22	4.48
VECOM4	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	7.41	7.57	58.48	4.41
VECOM5	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	5.66	7.31	31.63	4.49
VECOM6	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	7.11	8.08	43.34	4.83
VECOM7	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	6.41	7.39	55.92	4.57
VECOM8	Vancouver	Effluent	Storm Event	11/26/1998	Soluble	9.64	7.38	50.49	4.23
VICOM1	Vancouver	Influent	Storm Event	11/26/1998	Total	18.36	26.85	118.22	0.73
VICOM4	Vancouver	Influent	Storm Event	11/26/1998	Total	14.38	16.54	115.70	0.65
VICOM5	Vancouver	Influent	Storm Event	11/26/1998	Total	13.88	16.76	87.44	0.49
VICOM6	Vancouver	Influent	Storm Event	11/26/1998	Total	9.27	8.61	68.89	0.35
VICOM7	Vancouver	Influent	Storm Event	11/26/1998	Total	11.07	9.47	149.25	0.48
VICOM8	Vancouver	Influent	Storm Event	11/26/1998	Total	10.00	9.62	74.73	0.49
VICOM9	Vancouver	Influent	Storm Event	11/26/1998	Total	10.97	9.22	85.84	0.41
VICOM10	Vancouver	Influent	Storm Event	11/26/1998	Total	6.74	3.45	54.40	0.19
VICOM11	Vancouver	Influent	Storm Event	11/26/1998	Total	8.47	5.68	74.07	0.28
VICOM12	Vancouver	Influent	Storm Event	11/26/1998	Total	7.75	5.79	66.65	0.27
VECOM1	Vancouver	Effluent	Storm Event	11/26/1998	Total	8.72	4.81	83.72	0.67
VECOM2	Vancouver	Effluent	Storm Event	11/26/1998	Total	7.43	4.63	64.02	0.91
VECOM3	Vancouver	Effluent	Storm Event	11/26/1998	Total	7.96	6.56	301.50	0.77
VECOM4	Vancouver	Effluent	Storm Event	11/26/1998	Total	7.47	4.75	67.48	0.59
VECOM5	Vancouver	Effluent	Storm Event	11/26/1998	Total	7.30	4.45	64.42	0.75
VECOM6	Vancouver	Effluent	Storm Event	11/26/1998	Total	6.84	4.28	80.24	0.55
VECOM7	Vancouver	Effluent	Storm Event	11/26/1998	Total	6.58	3.78	71.88	0.55
VECOM8	Vancouver	Effluent	Storm Event	11/26/1998	Total	7.19	3.96	93.22	0.81
SICOM1	Spokane	Influent	Storm Event	12/7/1998	Soluble	23.64	7.07	88.77	4.46

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SICOM2	Spokane	Influent	Storm Event	12/7/1998	Soluble	25.06	7.05	89.67	4.50
SICOM3	Spokane	Influent	Storm Event	12/7/1998	Soluble	27.43	7.11	105.49	4.41
SICOM4	Spokane	Influent	Storm Event	12/7/1998	Soluble	25.46	7.05	95.06	4.47
SICOM5	Spokane	Influent	Storm Event	12/7/1998	Soluble	27.56	7.09	115.29	4.47
SICOM6	Spokane	Influent	Storm Event	12/7/1998	Soluble	27.06	7.37	116.89	4.48
SICOM7	Spokane	Influent	Storm Event	12/7/1998	Soluble	26.86	7.09	125.29	4.42
SICOM8	Spokane	Influent	Storm Event	12/7/1998	Soluble	27.08	7.09	110.09	4.61
SECOM1	Spokane	Effluent	Storm Event	12/7/1998	Soluble	6.63	7.07	27.71	4.78
SECOM2	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.10	7.10	34.29	4.22
SECOM3	Spokane	Effluent	Storm Event	12/7/1998	Soluble	8.71	7.71	53.78	4.98
SECOM4	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.53	7.17	40.24	4.32
SECOM5	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.93	7.59	116.49	4.39
SECOM6	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.37	7.16	39.98	4.23
SECOM7	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.30	7.21	28.06	4.29
SECOM8	Spokane	Effluent	Storm Event	12/7/1998	Soluble	7.27	7.14	27.34	4.32
SICOM1	Spokane	Influent	Storm Event	12/7/1998	Total	34.38	13.44	235.92	0.95
SICOM2	Spokane	Influent	Storm Event	12/7/1998	Total	40.61	16.32	273.20	1.19
SICOM3	Spokane	Influent	Storm Event	12/7/1998	Total	41.13	16.65	283.17	1.46
SICOM4	Spokane	Influent	Storm Event	12/7/1998	Total	36.86	14.26	272.52	0.94
SICOM7	Spokane	Influent	Storm Event	12/7/1998	Total	36.56	13.45	346.74	0.89
SICOM8	Spokane	Influent	Storm Event	12/7/1998	Total	39.57	17.44	352.39	1.11
SECOM1	Spokane	Effluent	Storm Event	12/7/1998	Total	8.56	3.11	104.81	1.11
SECOM2	Spokane	Effluent	Storm Event	12/7/1998	Total	7.62	2.58	83.94	0.32
SECOM3	Spokane	Effluent	Storm Event	12/7/1998	Total	10.26	4.73	127.46	0.62
SECOM4	Spokane	Effluent	Storm Event	12/7/1998	Total	7.71	2.59	126.07	0.47
SECOM5	Spokane	Effluent	Storm Event	12/7/1998	Total	7.97	2.23	153.34	0.59
SECOM6	Spokane	Effluent	Storm Event	12/7/1998	Total	7.72	2.61	117.05	0.28
SECOM7	Spokane	Effluent	Storm Event	12/7/1998	Total	10.45	4.59	106.42	1.72
SECOM8	Spokane	Effluent	Storm Event	12/7/1998	Total	11.82	5.78	155.21	0.42
SICOM1	Spokane	Influent	Storm Event	1/16/1999	Soluble	10.13	7.06	22.03	4.23
SICOM2	Spokane	Influent	Storm Event	1/16/1999	Soluble	12.83	7.09	19.12	4.27
SICOM3	Spokane	Influent	Storm Event	1/16/1999	Soluble	9.73	7.01	17.55	4.29
SICOM4	Spokane	Influent	Storm Event	1/16/1999	Soluble	11.51	7.07	28.12	4.22
SICOM5	Spokane	Influent	Storm Event	1/16/1999	Soluble	16.87	7.23	30.99	4.36

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (μg/L)	Pb (μg/L)	Zn (μg/L)	Cd (μg/L)
SICOM6	Spokane	Influent	Storm Event	1/16/1999	Soluble	16.63	7.13	26.72	4.31
SICOM7	Spokane	Influent	Storm Event	1/16/1999	Soluble	12.34	7.00	25.11	4.35
SICOM8	Spokane	Influent	Storm Event	1/16/1999	Soluble	17.77	7.14	33.51	4.35
SECOM1	Spokane	Effluent	Storm Event	1/16/1999	Soluble	9.13	7.03	20.34	4.28
SECOM2	Spokane	Effluent	Storm Event	1/16/1999	Soluble	8.99	7.01	19.24	4.24
SECOM3	Spokane	Effluent	Storm Event	1/16/1999	Soluble	10.17	7.07	25.14	4.52
SECOM4	Spokane	Effluent	Storm Event	1/16/1999	Soluble	10.10	7.34	30.94	4.24
SECOM5	Spokane	Effluent	Storm Event	1/16/1999	Soluble	8.46	7.03	23.20	4.30
SECOM6	Spokane	Effluent	Storm Event	1/16/1999	Soluble	9.63	7.06	20.06	4.21
SECOM7	Spokane	Effluent	Storm Event	1/16/1999	Soluble	9.72	7.21	20.19	4.42
SECOM8	Spokane	Effluent	Storm Event	1/16/1999	Soluble	9.73	7.23	20.43	4.23
SICOM1	Spokane	Influent	Storm Event	1/16/1999	Total	114.67	145.67	1065.53	4.28
SICOM2	Spokane	Influent	Storm Event	1/16/1999	Total	85.23	99.67	595.24	2.82
SICOM3	Spokane	Influent	Storm Event	1/16/1999	Total	36.77	34.09	286.81	1.11
SICOM4	Spokane	Influent	Storm Event	1/16/1999	Total	40.92	33.43	300.53	1.14
SICOM5	Spokane	Influent	Storm Event	1/16/1999	Total	48.53	48.08	390.99	1.46
SICOM6	Spokane	Influent	Storm Event	1/16/1999	Total	55.03	46.30	438.64	1.57
SICOM7	Spokane	Influent	Storm Event	1/16/1999	Total	50.36	42.11	349.23	1.27
SECOM1	Spokane	Effluent	Storm Event	1/16/1999	Total	14.23	6.73	100.44	0.59
SECOM2	Spokane	Effluent	Storm Event	1/16/1999	Total	9.75	2.14	60.63	0.25
SECOM3	Spokane	Effluent	Storm Event	1/16/1999	Total	9.86	2.21	71.47	1.15
SECOM4	Spokane	Effluent	Storm Event	1/16/1999	Total	9.92	2.32	64.93	0.40
SECOM5	Spokane	Effluent	Storm Event	1/16/1999	Total	10.08	2.25	87.29	0.45
SECOM6	Spokane	Effluent	Storm Event	1/16/1999	Total	9.99	2.35	102.89	0.34
SECOM7	Spokane	Effluent	Storm Event	1/16/1999	Total	14.29	2.19	73.71	0.55
SECOM8	Spokane	Effluent	Storm Event	1/16/1999	Total	10.66	1.93	67.58	0.28
VICOM1	Vancouver	Influent	Storm Event	1/17/1999	Soluble	6.72	7.31	26.40	4.26
VICOM2	Vancouver	Influent	Storm Event	1/17/1999	Soluble	6.65	7.16	24.90	4.20
VICOM3	Vancouver	Influent	Storm Event	1/17/1999	Soluble	6.29	7.46	25.78	4.34
VICOM4	Vancouver	Influent	Storm Event	1/17/1999	Soluble	6.78	7.91	32.71	4.24
VICOM5	Vancouver	Influent	Storm Event	1/17/1999	Soluble	6.16	7.24	28.63	4.15
VICOM6	Vancouver	Influent	Storm Event	1/17/1999	Soluble	5.98	7.23	26.99	4.16
VICOM7	Vancouver	Influent	Storm Event	1/17/1999	Soluble	5.85	7.20	27.97	4.19
VECOM1	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.86	7.23	49.61	4.43

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
VECOM2	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.13	7.26	35.07	4.25
VECOM3	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	5.80	7.21	37.23	4.21
VECOM4	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.61	7.28	53.31	4.21
VECOM5	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.05	7.26	34.31	4.19
VECOM6	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.14	7.27	47.76	4.19
VECOM7	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.04	7.26	36.93	4.19
VECOM8	Vancouver	Effluent	Storm Event	1/17/1999	Soluble	6.27	7.27	36.49	4.34
VICOM1	Vancouver	Influent	Storm Event	1/17/1999	Total	14.97	12.39	108.91	0.92
VICOM2	Vancouver	Influent	Storm Event	1/17/1999	Total	19.37	14.09	100.13	1.63
VICOM3	Vancouver	Influent	Storm Event	1/17/1999	Total	13.32	12.00	308.82	0.45
VICOM4	Vancouver	Influent	Storm Event	1/17/1999	Total	14.48	13.59	92.68	0.89
VICOM5	Vancouver	Influent	Storm Event	1/17/1999	Total	10.80	8.71	73.14	0.52
VICOM6	Vancouver	Influent	Storm Event	1/17/1999	Total	14.00	14.23	93.35	0.48
VICOM7	Vancouver	Influent	Storm Event	1/17/1999	Total	13.99	14.24	94.66	0.43
VECOM1	Vancouver	Effluent	Storm Event	1/17/1999	Total	16.23	13.42	228.75	1.40
VECOM2	Vancouver	Effluent	Storm Event	1/17/1999	Total	13.54	12.48	265.98	0.56
VECOM3	Vancouver	Effluent	Storm Event	1/17/1999	Total	13.98	14.57	133.94	0.50
VECOM4	Vancouver	Effluent	Storm Event	1/17/1999	Total	15.07	15.34	178.41	0.67
VECOM5	Vancouver	Effluent	Storm Event	1/17/1999	Total	14.27	14.99	191.83	0.61
VECOM6	Vancouver	Effluent	Storm Event	1/17/1999	Total	13.84	14.39	209.58	0.54
VECOM7	Vancouver	Effluent	Storm Event	1/17/1999	Total	11.52	10.28	242.27	0.51
VECOM8	Vancouver	Effluent	Storm Event	1/17/1999	Total	12.50	10.39	145.54	1.84
SICOM1	Spokane	Influent	Storm Event	2/16/1999	Soluble	30.40	7.35	26.56	4.34
SICOM2	Spokane	Influent	Storm Event	2/16/1999	Soluble	24.12	7.57	29.75	4.62
SICOM3	Spokane	Influent	Storm Event	2/16/1999	Soluble	20.27	7.08	22.24	4.24
SICOM4	Spokane	Influent	Storm Event	2/16/1999	Soluble	19.25	7.06	22.39	4.26
SICOM5	Spokane	Influent	Storm Event	2/16/1999	Soluble	21.33	9.19	26.93	6.17
SICOM6	Spokane	Influent	Storm Event	2/16/1999	Soluble	17.57	7.06	20.57	4.23
SICOM7	Spokane	Influent	Storm Event	2/16/1999	Soluble	16.73	7.09	22.74	4.24
SICOM8	Spokane	Influent	Storm Event	2/16/1999	Soluble	15.31	7.09	25.98	4.25
SECOM1	Spokane	Effluent	Storm Event	2/16/1999	Soluble	8.00	7.02	19.04	4.26
SECOM2	Spokane	Effluent	Storm Event	2/16/1999	Soluble	19.56	13.53	40.76	9.93
SECOM3	Spokane	Effluent	Storm Event	2/16/1999	Soluble	12.24	9.22	63.98	4.32
SECOM4	Spokane	Effluent	Storm Event	2/16/1999	Soluble	7.71	7.03	16.81	4.37

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SECOM5	Spokane	Effluent	Storm Event	2/16/1999	Soluble	8.42	7.03	16.22	4.52
SECOM6	Spokane	Effluent	Storm Event	2/16/1999	Soluble	7.63	7.06	14.50	4.21
SECOM7	Spokane	Effluent	Storm Event	2/16/1999	Soluble	7.79	7.03	21.64	4.33
SECOM8	Spokane	Effluent	Storm Event	2/16/1999	Soluble	13.97	10.22	97.02	6.93
SICOM1	Spokane	Influent	Storm Event	2/16/1999	Total	146.63	158.48	1176.57	5.01
SICOM2	Spokane	Influent	Storm Event	2/16/1999	Total	131.30	133.85	1028.24	4.27
SICOM3	Spokane	Influent	Storm Event	2/16/1999	Total	165.01	177.41	1289.24	5.39
SICOM4	Spokane	Influent	Storm Event	2/16/1999	Total	196.13	229.60	1940.68	6.66
SICOM5	Spokane	Influent	Storm Event	2/16/1999	Total	161.74	178.23	1322.73	5.34
SICOM6	Spokane	Influent	Storm Event	2/16/1999	Total	130.32	138.29	1034.26	4.56
SICOM7	Spokane	Influent	Storm Event	2/16/1999	Total	126.59	134.96	1103.52	4.55
SICOM8	Spokane	Influent	Storm Event	2/16/1999	Total	113.55	122.66	994.38	4.39
SECOM1	Spokane	Effluent	Storm Event	2/16/1999	Total	10.19	3.61	87.86	0.49
SECOM2	Spokane	Effluent	Storm Event	2/16/1999	Total	11.48	2.64	110.46	0.65
SECOM3	Spokane	Effluent	Storm Event	2/16/1999	Total	4.93	nd	17.15	0.26
SECOM4	Spokane	Effluent	Storm Event	2/16/1999	Total	9.30	1.84	61.81	0.62
SECOM5	Spokane	Effluent	Storm Event	2/16/1999	Total	11.39	2.42	69.05	1.26
SECOM6	Spokane	Effluent	Storm Event	2/16/1999	Total	9.16	1.91	79.95	0.29
SECOM7	Spokane	Effluent	Storm Event	2/16/1999	Total	13.09	2.15	117.01	0.50
SECOM8	Spokane	Effluent	Storm Event	2/16/1999	Total	8.43	2.02	192.55	0.65
SICOM1	Spokane	Influent	Storm Event	3/25/1999	Soluble	12.55	2.30	44.78	nd
SICOM2	Spokane	Influent	Storm Event	3/25/1999	Soluble	15.94	1.84	44.55	nd
SICOM3	Spokane	Influent	Storm Event	3/25/1999	Soluble	12.81	1.81	21.40	nd
SICOM4	Spokane	Influent	Storm Event	3/25/1999	Soluble	7.34	1.72	19.58	nd
SICOM5	Spokane	Influent	Storm Event	3/25/1999	Soluble	5.44	1.83	23.34	nd
SICOM6	Spokane	Influent	Storm Event	3/25/1999	Soluble	5.34	1.71	19.74	nd
SICOM7	Spokane	Influent	Storm Event	3/25/1999	Soluble	5.63	1.67	26.78	nd
SICOM8	Spokane	Influent	Storm Event	3/25/1999	Soluble	3.46	2.74	232.99	nd
SECOM1	Spokane	Effluent	Storm Event	3/25/1999	Soluble	1.62	1.58	13.15	nd
SECOM2	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.22	10.40	11.49	6.99
SECOM3	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.49	10.29	14.17	6.97
SECOM4	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.97	10.43	32.94	7.06
SECOM5	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.48	10.32	17.09	6.94
SECOM6	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.60	10.30	21.17	7.01

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SECOM7	Spokane	Effluent	Storm Event	3/25/1999	Soluble	10.04	10.20	17.29	6.88
SICOM1	Spokane	Influent	Storm Event	3/25/1999	Total	45.77	53.91	536.39	nd
SICOM2	Spokane	Influent	Storm Event	3/25/1999	Total	83.29	85.26	794.99	nd
SICOM3	Spokane	Influent	Storm Event	3/25/1999	Total	78.56	88.97	756.79	nd
SICOM4	Spokane	Influent	Storm Event	3/25/1999	Total	28.71	30.96	292.89	nd
SICOM5	Spokane	Influent	Storm Event	3/25/1999	Total	7.04	7.05	104.59	nd
SICOM6	Spokane	Influent	Storm Event	3/25/1999	Total	5.41	2.43	92.98	nd
SICOM7	Spokane	Influent	Storm Event	3/25/1999	Total	7.46	4.18	119.29	nd
SICOM8	Spokane	Influent	Storm Event	3/25/1999	Total	nd	1.48	39.11	nd
SECOM1	Spokane	Effluent	Storm Event	3/25/1999	Total	nd	nd	64.35	nd
SECOM2	Spokane	Effluent	Storm Event	3/25/1999	Total	nd	0.56	30.33	nd
SECOM3	Spokane	Effluent	Storm Event	3/25/1999	Total	12.78	4.74	53.39	nd
SECOM4	Spokane	Effluent	Storm Event	3/25/1999	Total	nd	nd	54.99	nd
SECOM5	Spokane	Effluent	Storm Event	3/25/1999	Total	nd	nd	74.05	nd
SECOM6	Spokane	Effluent	Storm Event	3/25/1999	Total	nd	nd	74.38	nd
SICOM1	Spokane	Influent	Storm Event	4/3/1999	Soluble	18.54	7.10	50.39	4.51
SICOM2	Spokane	Influent	Storm Event	4/3/1999	Soluble	11.92	6.99	31.09	4.31
SICOM3	Spokane	Influent	Storm Event	4/3/1999	Soluble	14.13	7.07	43.64	4.29
SICOM4	Spokane	Influent	Storm Event	4/3/1999	Soluble	11.71	7.05	39.50	4.24
SICOM5	Spokane	Influent	Storm Event	4/3/1999	Soluble	10.74	7.06	28.96	4.24
SICOM6	Spokane	Influent	Storm Event	4/3/1999	Soluble	10.66	7.08	40.95	4.22
SICOM7	Spokane	Influent	Storm Event	4/3/1999	Soluble	11.41	7.16	29.15	4.43
SECOM1	Spokane	Effluent	Storm Event	4/3/1999	Soluble	8.95	7.82	20.90	4.94
SECOM2	Spokane	Effluent	Storm Event	4/3/1999	Soluble	9.14	8.04	18.70	4.58
SECOM3	Spokane	Effluent	Storm Event	4/3/1999	Soluble	9.36	8.59	14.03	4.52
SECOM4	Spokane	Effluent	Storm Event	4/3/1999	Soluble	9.86	8.25	23.23	4.50
SECOM5	Spokane	Effluent	Storm Event	4/3/1999	Soluble	10.12	10.19	13.27	4.68
SECOM6	Spokane	Effluent	Storm Event	4/3/1999	Soluble	10.40	7.52	46.47	4.29
SECOM7	Spokane	Effluent	Storm Event	4/3/1999	Soluble	7.54	7.10	8.27	4.31
SECOM8	Spokane	Effluent	Storm Event	4/3/1999	Soluble	8.61	7.12	15.16	4.23
SICOM1	Spokane	Influent	Storm Event	4/3/1999	Total	30.10	18.97	179.87	0.82
SICOM2	Spokane	Influent	Storm Event	4/3/1999	Total	27.20	14.15	153.88	0.65
SICOM3	Spokane	Influent	Storm Event	4/3/1999	Total	20.35	7.03	115.67	0.60
SICOM4	Spokane	Influent	Storm Event	4/3/1999	Total	18.15	6.71	115.22	0.49

sample ID	sample location	pond location	sample type	sample date	analysis type	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
SICOM5	Spokane	Influent	Storm Event	4/3/1999	Total	15.28	5.50	98.02	0.50
SICOM6	Spokane	Influent	Storm Event	4/3/1999	Total	15.14	8.33	82.25	0.70
SICOM7	Spokane	Influent	Storm Event	4/3/1999	Total	15.43	4.79	127.18	0.59
SICOM8	Spokane	Influent	Storm Event	4/3/1999	Total	16.20	6.53	104.32	1.09
SECOM1	Spokane	Effluent	Storm Event	4/3/1999	Total	13.46	9.60	76.07	1.19
SECOM3	Spokane	Effluent	Storm Event	4/3/1999	Total	11.14	9.18	40.41	0.78
SECOM4	Spokane	Effluent	Storm Event	4/3/1999	Total	10.97	9.94	48.64	1.05
SECOM5	Spokane	Effluent	Storm Event	4/3/1999	Total	1.38	nd	nd	nd
SECOM6	Spokane	Effluent	Storm Event	4/3/1999	Total	11.92	6.03	69.03	0.43
SECOM7	Spokane	Effluent	Storm Event	4/3/1999	Total	12.32	4.79	60.24	0.65
SECOM8	Spokane	Effluent	Storm Event	4/3/1999	Total	9.63	2.65	56.01	0.60

9 APPENDIX D – POND STORMWATER AND WATER COLUMN NUTRIENT DATA

Table 18. Spokane and Vancouver pond influent, effluent, and water column nutrient data.

Sample Name Legend: V – Vancouver pond; S – Spokane pond; I –stormwater inlet sample; E –stormwater pond outlet sample; COM# – refers to the sample number within a storm event, 1 is the first sample collected during the event, 2 is the second sample collected during the same event, etc. Sample Type Legend: storm – storm event samples; batch – sample collected from the in-pond batch reactors used to define nutrient reaction rate constants.

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
	spokane	influent	storm		9/14/97	4.58	1.09	7.894	0.52	0.216	99	183.97	52
SI9	spokane	influent	storm		9/14/97	5.02	1.42	5.322	0.48	0.124	99	121.61	82
SI18	spokane	influent	storm		9/14/97	2.07	0.43	5.083	0.33	0.164	119	81.07	1497 (gravel)
SI17	spokane	influent	storm		9/14/97	1.85	0.43	5.132	0.52	0.194	116	112.25	27
SI16	spokane	influent	storm		9/14/97	1.75	0.55	4.819	0.29	0.205	114	46.77	17
SI15	spokane	influent	storm		9/14/97	4.15	0.32	5.93	0.37	0.222	113	56.13	17
SI14	spokane	influent	storm		9/14/97	2.4	0.43	6.486	0.33	0.221	113	59.24	15
SI13	spokane	influent	storm		9/14/97	3.05	0.43	5.722	0.40	0.233	109	65.48	23
SI12	spokane	influent	storm		9/14/97	4.69	0.64	7.338	0.49	0.247	98	102.90	32
SI10	spokane	influent	storm		9/14/97	5.11	1.19	4.104	0.83	0.102	76	236.98	184
SI21	spokane	influent	storm		9/14/97	5.88	1.19	6.993	0.55	0.208	91	143.43	66
SI8	spokane	influent	storm		9/14/97	9.37	2.49	6.861	0.60	0.194	96	137.20	79
SI7	spokane	influent	storm		9/14/97	8.28	3.26	6.887	0.81	0.183	91	180.85	131
SI6	spokane	influent	storm		9/14/97	12.2	5.23	6.463	0.80	0.161	93	199.56	183
SI5	spokane	influent	storm		9/14/97	7.41	1.19	6.252	0.97	0.091	87	218.27	201
SI4	spokane	influent	storm		9/14/97	10.13	0.98	5.616	1.21	0.088	85	261.92	252
SI3	spokane	influent	storm		9/14/97	6.11	1.68	5.139	0.87	0.109	104	205.80	362
SI2	spokane	influent	storm		9/14/97	7.73	1.3	5.907	0.80	0.124	113	205.80	268
SI1	spokane	influent	storm		9/14/97	3.6	0.32	6.781	0.45	0.231	106	93.54	24
SI11	spokane	effluent	storm		9/14/97	1.74	0.43	4.062	0.30	0.158	123	34.3	13
SE5	spokane	effluent	storm		9/14/97	0.43	0.049	3.718	0.15	0.139	124	81.1	5
SE17	spokane	effluent	storm		9/14/97	2.49	0.049	3.43	0.15	0.138	123	90.4	7
SE16	spokane	effluent	storm		9/14/97	1.49	0.11	3.603	0.14	0.138	127	18.7	7
SE15	spokane	effluent	storm		9/14/97	0.21	0.049	3.646	0.16	0.138	124	18.7	4
SE13	spokane	effluent	storm		9/14/97	2.69	0.049	3.301	0.15	0.139	126	81.1	6
SE11	spokane	effluent	storm		9/14/97	2.49	0.049	3.675	0.16	0.150	122	28.1	9

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SE10	spokane	effluent	storm		9/14/97	1.19	0.049	3.617	0.16	0.145	123	9.4	10
SE9	spokane	effluent	storm		9/14/97	1.19	0.049	3.43	0.17	0.145	124	21.8	9
SE8	spokane	influent	storm		9/14/97	3.38	2.83	5.851	0.64	0.120	92	187.09	114
SI19	spokane	effluent	storm		9/14/97	2.07	0.34	4.005	0.19	0.153	124	34.3	12
SE6	spokane	influent	storm		9/14/97	5.11	1.53	4.766	0.51	0.103	83	180.85	162
SI20	spokane	effluent	storm		9/14/97	2.72	0.049	4.105	0.22	0.159	126	37.4	11
SE4	spokane	effluent	storm		9/14/97	3.26	0.049	4.119	0.22	0.166	124	74.8	15
SE3	spokane	effluent	storm		9/14/97	4.36	0.22	3.904	0.22	0.155	123	21.8	12
SE2	spokane	effluent	storm		9/14/97	2.4	0.22	3.617	0.25	0.142	123	31.2	31
SE1	spokane	influent	storm		9/14/97	5.23	0.98	4.077	0.89	0.155	65	165.26	155
SI24	spokane	influent	storm		9/14/97	3.38	0.64	4.157	0.67	0.136	65	177.73	153
SI23	spokane	influent	storm		9/14/97	7.08	1.3	3.971	1.24	0.136	69	180.85	190
SI22	spokane	effluent	storm		9/14/97	2.94	0.049	3.373	0.16	0.134	123	12.5	4
SE12	spokane	effluent	storm		9/14/97	3.38	0.049	3.761	0.19	0.147	125	28.1	11
SE7	spokane	effluent	storm		9/14/97	0.98	0.11	3.675	0.14	0.136	123	34.3	8
SE14	spokane	effluent	storm		9/15/97	0.43	0.049	3.732	0.14	0.139	126	78.0	6
SE18	spokane	effluent	storm		9/15/97	0.98	0.049	3.789	0.13	0.142	124	53.0	4
SE19	spokane	effluent	storm		9/15/97	2.28	0.34	3.832	0.15	0.139	123	140.3	7
SE20	spokane	effluent	storm		9/15/97	1.18	0.049	3.789	0.15	0.141	123	31.2	5
SE21	spokane	effluent	storm		9/15/97	0.21	0.22	3.344	0.14	0.141	123	56.1	3
SE22	spokane	effluent	storm		9/15/97	0.28	0.34	3.416	0.14	0.141	123	24.9	4
SE23	spokane	effluent	storm		9/15/97	0.53	0.049	3.89	0.14	0.136	125	15.6	7
SE24	Spokane	effluent	storm		10/26/97	0.049	0.11	2.681	0.30	0.102	118	65.5	3
SECOM4	Spokane	influent	storm		10/26/97	2.17	1.42	4.118	0.10	0.194	113	53.0	15
SICOM2	Spokane	influent	storm		10/26/97	1.96	1.21	5.804	0.11	0.167	114	44.4	17
SICOM3	Spokane	influent	storm		10/26/97	1.53	0.87	5.638	0.11	0.153	120	62.4	18
SICOM4	Spokane	influent	storm		10/26/97	0.64	0.32	4.478	0.11	0.170	118	9.4	12
SICOM5	Spokane	influent	storm		10/26/97	0.43	0.22	3.842	0.11	0.177	121	7.9	5
SICOM6	Spokane	influent	storm		10/26/97	0.11	0.11	3.842	0.11	0.178	124	9.4	3
SICOM7	Spokane	influent	storm		10/26/97	2.17	1.53	5.252	0.12	0.231	114	21.8	19
SICOM1	Spokane	effluent	storm		10/26/97	0.049	0.11	2.64	0.31	0.099	119	53.0	1
SECOM3	Spokane	influent	storm		10/26/97	0.11	0.11	3.842	0.10	0.170	127	18.7	5

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SICOM8	Spokane	effluent	storm		10/26/97	0.21	0.049	2.57	0.25	0.100	118	24.9	4
SECOM5	Spokane	effluent	storm		10/26/97	0.21	0.22	2.57	0.19	0.102	119	12.5	3
SECOM6	Spokane	effluent	storm		10/26/97	0.049	0.22	2.543	0.20	0.100	120	12.5	3
SECOM7	Spokane	effluent	storm		10/26/97	0.21	0.11	2.515	0.20	0.102	118	18.7	1
SECOM8	Spokane	effluent	storm		10/26/97	0.32	0.049	2.902	0.38	0.103	120	65.5	5
SECOM1	Spokane	effluent	storm		10/26/97	0.21	0.22	2.57	0.31	0.102	117	59.2	2
SECOM2	vancouver	dead zone	water column	bottom	11/25/97	28.3	0.05	3.847	0.4597	0.003	7.6	561.809	488
VDWCB	vancouver	influent	water column	bottom	11/25/97	0.98	0.05	4.019	0.0634	0.003	6.2	303.680	116
VIWCB	vancouver	dead zone	water column	top	11/25/97	0.32	0.05	3.746	0.044	0.003	3.4	27.331	28
VDWCT	vancouver	influent	water column	top	11/25/97	1.23	0.11	3.832	0.0761	0.003	16.6	36.442	34
VIWCT	vancouver	effluent	water column	top	11/25/97	2.15	0.05	4.22	0.0444	0.003	4.6	24.294	25
VEWCT	vancouver	effluent	water column	bottom	11/25/97	1.63	0.05	4.378	0.0571	0.003	4.4	39.478	73
VEWCB	spokane	influent	water column	top	12/10/97	0.34	0.05	3.746	0.05	0.019	126	27.331	94
SIWCT	spokane	dead zone	water column	top	12/10/97	0.22	0.05	4.378	0.04	0.019	120	27.331	70
SDWCT	spokane	influent	water column	bottom	12/10/97	0.11	0.05	4.22	0.07	0.019	122	51.626	92
SIWCB	spokane	effluent	water column	top	12/10/97	0.55	0.05	4.019	0.06	0.021	118	18.221	122
SEWCT	spokane	effluent	water column	bottom	12/10/97	0.77	0.05	3.832	0.16	0.016	120	48.589	238
SEWCB	spokane	dead zone	water column	bottom	12/10/97	0.66	0.05	3.847	0.07	0.021	125	48.589	148
SDWCB	Spokane	influent	storm		12/15/97	1.3	0.049	2.875	0.02	0.024	119	154.877	320
SICOM2	Spokane	influent	storm		12/15/97	2.28	0.049	2.764	0.03	0.030	115	148.803	319
SICOM1	Spokane	effluent	storm		12/16/97	0.11	0.11	3.761	0.09	0.051	106	24.294	60

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SECOM4	Spokane	influent	storm		12/16/97	0.11	0.049	4.063	0.09	0.022	124	54.662	111
SICOM6	Spokane	effluent	storm		12/16/97	0.87	0.43	7.464	0.18	0.061	112	24.294	57
SECOM1	Spokane	effluent	storm		12/16/97	0.55	0.21	6.545	0.11	0.053	107	21.258	70
SECOM3	Spokane	effluent	storm		12/16/97	0.11	0.21	4.363	0.11	0.059	111	21.258	43
SECOM2	Spokane	effluent	storm		12/16/97	0.87	0.11	3.359	0.12	0.049	108	27.331	50
SECOM5	Spokane	influent	storm		12/16/97	1.09	0.049	3.4	0.02	0.018	116	139.693	206
SICOM3	Spokane	influent	storm		12/16/97	1.19	0.049	3.759	0.06	0.016	131	103.251	215
SICOM4	Spokane	influent	storm		12/16/97	0.11	0.049	4.256	0.04	0.022	127	45.552	127
SICOM5	Spokane	effluent	storm		12/16/97	0.32	0.11	4.091	0.16	0.051	113	21.258	69
SECOM6	vancouver	effluent	storm		1/18/98	0.66	0.10	0.212	0.197	0.0161	8.8	56.453	72
VECOM5	vancouver	effluent	storm		1/18/98	0.55	0.05	0.450	0.178	0.0081	insuf sample	49.811	65
VECOM6	vancouver	influent	storm		1/18/98	1.53	0.05	1.050	0.342	0.0064	11.8	162.716	190
VICOM2	vancouver	effluent	storm		1/18/98	0.55	0.05	0.318	0.222	0.0145	10.9	46.49	58
VECOM4	vancouver	influent	storm		1/18/98	1.32	0.10	0.332	0.222	0.0064	insuf sample	112.905	116
VICOM5	vancouver	effluent	storm		1/18/98	0.55	0.05	0.583	0.12	0.0177	10.8	43.170	35
VECOM1	vancouver	effluent	storm		1/18/98	0.66	0.05	0.318	0.120	0.0145	8.9	53.132	36
VECOM3	vancouver	influent	storm		1/18/98	0.98	0.10	0.525	0.285	0.0064	9.8	109.584	136
VICOM3	vancouver	influent	storm		1/18/98	0.98	0.10	2.709	0.063	0.0113	20.7	53.132	16
VICOM1	vancouver	effluent	storm		1/18/98	0.66	0.05	0.053	0.127	0.0161	11.6	36.528	32
VECOM2	vancouver	influent	storm		1/18/98	1.09	0.05	0.359	0.216	0.0032	8.9	146.112	107
VICOM4	vancouver	effluent	storm		1/24/98	1.09	0.21	1.219	0.127	0.0097	9.835	76.377	41
VECOM1	vancouver	influent	storm		1/24/98	1.32	0.10	0.238	0.456	0.0064	11.704	205.886	322
VICOM1	vancouver	influent	storm		1/24/98	1.09	0.10	0.212	0.311	0.0081	8.753	126.188	198
VICOM2	vancouver	effluent	storm		1/24/98	1.09	0.21	0.768	0.178	0.0097	11.015	46.49	44
VECOM2	vancouver	influent	storm		1/24/98	1.32	0.05	0.185	0.292	0.0097	7.966	89.660	134
VICOM3	vancouver	influent	storm		1/24/98	0.66	0.05	0.371	0.146	0.0097	14.261	66.415	32
VICOM4	vancouver	influent	storm		1/24/98	1.21	0.21	0.424	0.228	0.0081	16.228	245.735	115
VICOM5	vancouver	influent	storm		1/24/98	1.21	0.10	0.371	0.317	0.0113	14.753	59.773	47.3
VICOM6	vancouver	effluent	storm		1/24/98	0.55	0.05	0.609	0.108	0.0113	11.504	23.245	22
VECOM5	vancouver	effluent	storm		1/24/98	0.88	0.10	0.874	0.165	0.011	9.540	29.887	23

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VECOM4	vancouver	effluent	storm		1/24/98	1.09	0.21	1.219	0.108	0.0097	7.180	73.056	29
VECOM3	vancouver	effluent	storm		1/24/98	0.88	0.05	2.305	0.178	0.0113	2.655	39.849	16
VECOM6	vancouver	influent	water column	top	1/25/98	0.77	0.10	0.185	0.106	0.0113	12.786	59.773	39
VIWCT	vancouver	dead zone	water column	bottom	1/25/98	0.77	0.10	0.344	0.068	0.0097	11.507	53.132	35
VDWCB	vancouver	influent	water column	bottom	1/25/98	0.66	0.10	0.159	0.070	0.0097	11.704	59.773	46
VIWCB	vancouver	effluent	water column	top	1/25/98	0.43	0.10	0.238	0.062	0.0097	12.097	46.49	31
VEWCT	vancouver	effluent	water column	bottom	1/25/98	1.09	0.10	0.238	0.093	0.0129	12.195	49.811	38
VEWCB	vancouver	dead zone	water column	top	1/25/98	1.09	0.10	0.397	0.076	0.0113	10.523	49.811	30
VDWCT	spokane	influent	water column	bottom	1/31/98	0.55	0.21	2.993	0.285	0.1450	116.053	19.411	54
SIWCB	spokane	influent	water column	top	1/31/98	1.42	0.21	3.046	0.209	0.1611	84.118	6.470	7
SIWCT	spokane	dead zone	water column	bottom	1/31/98	0.66	0.11	2.993	0.285	0.1660	114.479	19.411	53
SDWCB	spokane	effluent	water column	top	1/31/98	0.88	0.05	3.046	0.235	0.1611	115.856	25.881	25
SEWCT	spokane	dead zone	water column	top	1/31/98	0.88	0.11	2.437	0.368	0.1595	112.021	32.352	100
SDWCT	spokane	effluent	water column	bottom	1/31/98	1.42	0.32	2.967	0.533	0.1563	119.594	38.822	174
SEWCB	vancouver	influent	storm		2/8/98	1.3	0.34	3.338	0.130	0.0161	1.967	73.056	65
VICOM	vancouver	effluent	storm		2/28/98	1.19	0.53	0.715	0.05	0.008	6.196	39.019	12
VECOM3	vancouver	effluent	storm		2/28/98	1.19	0.53	0.677	0.081	0.01	8.753	13.006	8
VECOM8	vancouver	effluent	storm		2/28/98	1.30	0.53	0.677	0.062	0.01	9.835	61.780	6
VECOM7	vancouver	effluent	storm		2/28/98	1.19	0.53	0.564	0.056	0.010	8.950	9.755	9
VECOM6	vancouver	effluent	storm		2/28/98	1.19	0.53	0.753	0.05	0.011	9.343	13.006	4
VECOM5	vancouver	effluent	storm		2/28/98	1.19	0.43	0.790	0.05	0.006	9.147	9.755	8

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VECOM4	vancouver	effluent	storm		2/28/98	1.19	0.53	0.677	0.124	0.006	8.360	16.258	13
VECOM2	vancouver	effluent	storm		2/28/98	1.19	0.64	0.715	0.081	0.008	9.638	58.528	15
VECOM1	spokane	effluent	water column	bottom	3/16/98	1.08	1.96	3.425	0.416	0.0840	125.248	117.056	227
SEWCB	spokane	dead zone	water column	bottom	3/16/98	1.63	0.00	3.425	0.751	0.0727	129.162	6.503	362
SDWCB	spokane	influent	water column	bottom	3/16/98	0.87	0.53	3.646	0.236	0.0969	115.218	65.031	57
SIWCB	spokane	influent	water column	top	3/16/98	0.53	0.21	3.315	0.152	0.0921	120.356	16.258	3
SIWCT	spokane	effluent	water column	top	3/16/98	0.64	0.00	3.425	0.149	0.1018	116.931	13.006	6
SEWCT	spokane	dead zone	water column	top	3/16/98	0.53	0.00	3.241	0.118	0.0953	119.377	6.503	2
SDWCT	Spokane	control	batch	0 day	3/16/98	0.87	0.10	3.241	0.177	0.1303	99.318	32.516	40
SREACT0	Spokane	reactor 2	batch	0 day	3/16/98	2.07	0.10	3.280	0.919	0.1164	122.313	71.534	205
SREACT2	Spokane	reactor 3	batch	0 day	3/16/98	1.19	0.05	3.578	0.577	0.1257	120.111	55.276	286
SREACT3	Spokane	input	batch	0 day	3/16/98	44.89	2.83	0.031	0.577	0.1676	1092.985	3349.1	1946
SREACT4	Spokane	reactor 1	batch	0 day	3/16/98	0.98	0	3.446	0.447	0.1148	118.643	65.031	101
SREACT1	Spokane	reactor 2	batch	3 day	3/19/98	1.19	0.10	2.762	0.118	0.090	113.751	22.761	10
SREACT2	Spokane	reactor 1	batch	3 day	3/19/98	1.42	0.10	2.873	0.143	0.126	111.060	65.031	8
SREACT1	Spokane	Control	batch	3 day	3/19/98	2.61	0.10	2.505	0.329	0.116	121.089	32.516	31
SREACT0	Spokane	reactor 3	batch	3 day	3/19/98	1.08	0.05	2.726	0.143	0.096	119.622	19.509	7
SREACT3	vancouver	influent	water column	top	3/23/98	3.474	1.53	0.783	0.372	0.0450	15.167	84.540	154

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VIWCT	vancouver	influent	water column	bottom	3/23/98	3.152	1.53	0.783	0.186	0.0295	12.231	123.559	80
VIWCB	vancouver	effluent	water column	top	3/23/98	2.178	1.85	1.015	0.143	0.0233	13.699	198.345	90
VEWCT	vancouver	dead zone	water column	bottom	3/23/98	5.114	1.74	0.783	0.391	0.0217	14.188	182.087	244
VDWCB	vancouver	dead zone	water column	top	3/23/98	2.83	1.85	0.783	0.329	0.0450	15.167	81.289	84
VDWCT	vancouver	effluent	water column	bottom	3/23/98	2.718	1.74	0.841	0.137	0.0403	15.656	104.050	68
VEWCB	Spokane	reactor 1	batch	12 day	3/28/98	1.19	0.43	1.636	0.068	0.0357	87.331	16.258	23
SREACT11	Spokane	control	batch	0 day	3/28/98	0.98	0.21	2.447	0.112	0.0853	111.304	71.534	45
SREACT0	Spokane	reactor 1	batch	0 day	3/28/98	1.96	0.43	2.060	0.875	0.0698	102.743	55.276	216.0
SREACT1	Spokane	reactor 2	batch	0 day	3/28/98	1.63	0.55	2.726	0.708	0.1055	114.729	61.780	284.0
SREACT2	Spokane	input	batch	0 day	3/28/98	62.06	4.77	0.062	0.450	0.2809	667.772	1560.746	12890
SREACT4	Spokane	reactor 3	batch	0 day	3/28/98	1.96	0.43	2.787	0.583	0.1210	122.068	149.571	938.0
SREACT3	Spokane	reactor 2	batch	7 day	4/4/98	1.08	0.32	2.116	0.074	0.0403	101.764	9.755	16
SREACT2	Spokane	reactor 3	batch	7 day	4/4/98	1.08	0.32	2.116	0.174	0.0760	112.772	39.019	19
SREACT3	Spokane	Deposition	Deposition Box		4/4/98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	48
SDEPOBOX	Spokane	reactor 1	batch	7 day	4/4/98	1.42	0.55	1.432	0.219	0.1117	95.648	13.006	20
SREACT1	Spokane	control	batch	7 day	4/4/98	1.19	0.32	2.962	0.133	0.090	122.313	0.0	11
SREACT0	Spokane	reactor 2	batch	14 day	4/11/98	1.09	0.22	1.487	0.074	0.0233	81.46	16.258	3

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SREACT2	Spokane	reactor 3	batch	14 day	4/11/98	1.96	0.43	1.332	0.124	0.0559	109.347	0.0	2
SREACT3	Spokane	reactor 1	batch	14 day	4/11/98	1.64	0.22	0.96	0.130	0.0155	104.210	42.270	4
SREACT1	Spokane	control	batch	14 day	4/11/98	2.83	0.22	2.354	0.298	0.1334	104.455	15.966	44
SREACT0	Spokane	influent	interstitial		4/11/98	1.21	0.22	2.859	0.245	0.2110	137.724	16.258	8
SISTIT	Spokane	effluent	interstitial		4/11/98	6.11	4.26	0.094	0.872	0.5193	209.888	26.012	8
SESTIT	Spokane	dead zone	interstitial		4/11/98	3.05	1.96	0.408	0.320	0.2328	136.745	22.352	8
SDSTIT	Spokane	influent	Bulk sample		4/25/98								15.333
SIWC	Spokane	reactor 1	batch	28 day	4/25/98	1.53	0.22	0.121	0.127	0.0434	88.799	6.503	8
SREACT1	Spokane	reactor 3	batch	28 day	4/25/98	2.51	0.11	0.248	0.171	0.0279	93.202	26.012	15
SREACT3	Spokane	effluent	Bulk sample		4/25/98								20.667
SEWC	Spokane	reactor 2	batch	28 day	4/25/98	2.73	0.22	0.681	0.149	0.0372	98.339	3.252	12
SREACT2	Spokane	Dead zone	Bulk sample		4/25/98								19.5
SDWC	Spokane	dead zone	interstitial		5/9/98	1.09	0.22	2.292	0.127	0.1009	117.42	22.761	2
SDSTIT	Spokane	north spring	grab		5/9/98	1.77	0.22	3.242	0.168	0.1753	143.595	39.04	2
NSPRING	Spokane	reactor 2	batch	42 day	5/9/98	2.64	0.34	0.174	0.248	0.0047	77.791	65.031	29
SREACT2	Spokane	reactor 3	batch	42 day	5/9/98	3.73	0.34	0.174	0.223	0.0078	81.216	71.534	19
SREACT3	Spokane	influent	interstitial		5/9/98	1.09	0.22	2.560	0.096	0.0760	95.893	0.0	0
SISTIT	Spokane	effluent	interstitial		5/9/98	2.41	0.34	2.901	0.521	0.2747	129.407	42.270	107

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SESTIT	Spokane	influent	water column	top	5/9/98	2.64	0.43	2.218	0.084	0.0295	103.476	9.579	9
SIWCT	Spokane	influent	water column	bottom	5/9/98	1.96	0.66	2.582	0.118	0.0434	79.992	6.386	9
SIWCB	Spokane	effluent	water column	top	5/9/98	2.19	0.77	2.275	0.121	0.0326	99.073	12.772	15
SEWCT	Spokane	effluent	water column	bottom	5/9/98	2.19	0.66	2.105	0.102	0.0264	100.786	6.386	31
SEWCB	Spokane	dead zone	water column	top	5/9/98	2.83	0.66	2.262	0.130	0.0357	98.339	6.386	10
SDWCT	Spokane	reactor 1	batch	42 day	5/9/98	2.64	0.11	0.313	0.149	0.0016	97.312	22.761	8
SREACT1	Spokane	dead zone	water column	bottom	5/9/98	3.28	0.77	2.321	0.180	0.0481	100.296	25.545	42
SDWCB	spokane	deposition	deposition box		5/9/98								256
SDEPOBOX	Spokane	south spring	grab		5/9/98	1.77	0.11	5.205	0.161	0.1040	106.412	42.297	16
SSPRING	Spokane	inlet pipe	grab		5/9/98	2.41	0.43	3.925	0.196	0.166	132.342	26.029	3
SIPS	Spokane	influent	storm		5/13/98	7.73	1.75	2.860	1.651	0.0947	105.189	389.559	646.0
SICOM2	Spokane	influent	storm		5/13/98	6.32	1.64	2.625	1.055	0.1117	99.807	300.152	492.0
SICOM3	Spokane	influent	storm		5/13/98	7.52	1.53	3.762	1.757	0.1288	118.154	376.787	804.0
SICOM1	Spokane	influent	storm		5/14/98	8.50	1.21	2.829	1.217	0.0869	79.992	306.538	682.0
SICOM6	Spokane	effluent	storm		5/14/98	2.28	0.43	2.327	0.230	0.0264	91.734	51.090	54
SECOM6	Spokane	effluent	storm		5/14/98	2.40	0.43	2.273	0.230	0.0248	91.979	51.090	54
SECOM5	Spokane	effluent	storm		5/14/98	2.19	0.43	2.247	0.267	0.0295	97.361	73.442	52
SECOM4	Spokane	effluent	storm		5/14/98	2.28	0.43	2.332	0.223	0.0326	99.807	31.931	62
SECOM3	Spokane	effluent	storm		5/14/98	2.07	0.43	2.923	0.174	0.0264	103.232	25.545	54
SECOM2	Spokane	effluent	storm		5/14/98	2.94	0.43	2.598	0.391	0.0279	110.571	38.317	96
SECOM1	Spokane	influent	storm		5/14/98	6.21	1.42	2.398	1.061	0.0978	63.603	258.642	598.0
SICOM7	Spokane	effluent	storm		5/14/98	2.28	0.22	2.138	0.174	0.0248	91.001	38.317	38
SECOM8	Spokane	influent	storm		5/14/98	5.77	1.42	5.627	0.732	0.0884	90.267	223.518	294.0

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SICOM5	Spokane	influent	storm		5/14/98	6.32	1.53	4.140	0.770	0.0993	91.734	242.676	334.0
SICOM4	Spokane	influent	storm		5/14/98	3.49	1.32	3.382	1.142	0.0807	56.019	220.325	476.0
SICOM8	Spokane	effluent	storm		5/14/98	2.40	0.22	2.354	0.230	0.0388	91.490	31.931	44
SECOM7	vancouver	influent	storm		5/16/98	2.620	1.09	0.893	0.540	0.008	14.348	191.587	344
VICOM2	vancouver	influent	storm		5/16/98	1.864	0.67	0.839	0.919	0.009	13.111	159.655	168
VICOM3	vancouver	influent	storm		5/16/98	1.416	0.67	0.595	0.335	0.006	10.141	89.407	128
VICOM4	vancouver	influent	storm		5/16/98	1.528	0.87	0.758	0.646	0.006	13.606	127.724	116
VICOM5	vancouver	influent	storm		5/16/98	1.752	0.87	1.678	0.447	0.011	10.390	130.917	124
VICOM6	vancouver	influent	storm		5/16/98	2.186	1.32	0.974	0.912	0.008	18.058	111.759	288
VICOM1	vancouver	influent	water column	bottom	5/17/98	1.094	0.55	1.082	0.112	0.011	3.760	6.386	31
VIWCB	vancouver	influent	interstitial		5/17/98	1.094	0.55	0.325	0.13	0.016	71.739	35.124	
VISTIT	vancouver	dead zone	interstitial		5/17/98	0.658	0.55	0.271	0.13	0.006	24.985	15.966	
VDSTIT	vancouver	influent	water column	top	5/17/98	1.106	0.55	0.568	0.093	0.014	5.244	12.772	19
VIWCT	vancouver	effluent	water column	top	5/17/98	0.884	0.43	0.920	0.223	0.016	4.849	15.966	19
VEWCT	vancouver	dead zone	water column	top	5/17/98	1.640	0.43	0.704	0.106	0.014	4.552	57.476	45
VDWCT	vancouver	dead zone	water column	bottom	5/17/98	1.528	0.55	1.660	0.447	0.011	2.078	25.545	42
VDWCB	vancouver	deposition	deposition box		5/17/98								256
VDEPOBOX	vancouver	effluent	water column	bottom	5/17/98	0.882	0.43	0.704	0.174	0.008	5.640	9.579	19
VEWCB	Spokane	effluent	storm		5/26/98	1.08	0.21	1.540	0.130	0.0636	74.213	22.776	25
SECOM3	Spokane	effluent	storm		5/26/98	1.19	0.32	1.385	0.155	0.0621	74.213	32.537	27
SECOM1	Spokane	effluent	storm		5/26/98	1.08	0.21	1.548	0.124	0.0605	76.686	42.297	16
SECOM2	Spokane	effluent	storm		5/26/98	0.87	0.32	1.459	0.158	0.0636	74.213	19.522	44
SECOM4	Spokane	effluent	storm		5/26/98	1.08	0.32	1.437	0.149	0.0683	70.255	58.566	45.3
SECOM5	Spokane	effluent	storm		5/26/98	0.98	0.32	1.245	0.155	0.0636	71.986	29.283	40

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SECOM6	Spokane	influent	storm		5/26/98	1.08	0.32	3.390	0.186	0.0683	102.166	42.297	24
SICOM8	Spokane	effluent	storm		5/26/98	0.64	0.32	1.267	0.155	0.0667	74.460	22.776	39
SECOM7	Spokane	influent	storm		5/26/98	1.30	0.32	2.889	0.372	0.0822	100.434	48.805	47
SICOM1	Spokane	influent	storm		5/26/98	1.08	0.21	5.295	0.211	0.0900	95.734	35.79	29
SICOM7	Spokane	influent	storm		5/26/98	1.08	0.21	5.204	0.217	0.0919	95.982	35.79	27
SICOM6	Spokane	influent	storm		5/26/98	0.64	0.43	2.579	0.236	0.0900	101.919	81.341	27
SICOM5	Spokane	influent	storm		5/26/98	0.87	0.21	2.977	0.180	0.0869	100.682	48.805	27
SICOM4	Spokane	influent	storm		5/26/98	0.87	0.21	2.476	0.217	0.0869	100.434	71.58	28
SICOM3	Spokane	influent	storm		5/26/98	1.19	0.32	3.397	0.223	0.0822	97.218	84.595	35
SICOM2	Spokane	effluent	storm		5/26/98	0.87	0.43	1.400	0.155	0.0652	73.470	26.029	37
SECOM8	vancouver	influent	storm		6/15/98	3.92	0.34	0.548	0.720	0.0031	13.853	181.499	362
VICOM1	vancouver	influent	storm		6/15/98	2.73	0.55	2.86	0.335	0.014	8.658	66.549	112
VICOM2	vancouver	influent	interstitial		7/2/98				0.081			38.763	
VISTIT	vancouver	dead zone	interstitial		7/2/98				0.053			29.073	
VDSTIT	vancouver	influent	water column	top	7/2/98				0.096			32.303	10
VIWCT	vancouver	influent	water column	bottom	7/2/98				0.106			54.915	11
VIWCB	vancouver	effluent	water column	top	7/2/98				0.115			41.994	30
VEWCT	vancouver	effluent	water column	bottom	7/2/98				0.137			54.915	28
VEWCB	vancouver	effluent	interstitial		7/2/98				0.118			100.139	
VESTIT	spokane	dead zone	interstitial		7/8/98	1.08	0.11	1.446	0.242	0.1676	107.608	12.921	
SDSTIT	spokane	influent	interstitial		7/8/98	1.08	0.11	2.022	0.071	0.0481	98.703	9.691	
SISTIT	spokane	reactor 3	batch		7/8/98	2.06	0.66	0.367	0.137	0.0729	108.103	67.836	12
SREACT3	spokane	reactor 1	batch		7/8/98	10.68	0.43	1.341	0.164	0.0047	108.845	64.606	42
SREACT1	spokane	dead zone	water column	bottom	7/8/98	1.08	0.22	1.718	0.062	0.0233	121.214	9.691	14

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SDWCB	spokane	influent	water column	top	7/8/98	2.28	0.55	1.247	0.338	0.0093	110.329	32.303	74
SIWCT	spokane	reactor 2	batch		7/8/98	11.11	5.02	0.000	1.539	0.6688	128.635	135.672	68
SREACT2	spokane	dead zone	water column	top	7/8/98	1.85	0.43	1.603	0.180	0.0155	108.598	38.763	46
SDWCT	spokane	effluent	water column	bottom	7/8/98	1.08	0.11	1.614	0.071	0.0233	117.503	22.612	23
SEWCB	spokane	effluent	interstitial		7/8/98	1.30	0.34	2.012	0.853	0.5788	155.599	16.151	
SESTIT	spokane	influent	water column	bottom	7/8/98	0.87	0.34	2.860	0.062	0.0140	117.503	29.073	37
SIWCB	spokane	effluent	water column	top	7/8/98	1.19	0.22	1.341	0.102	0.0109	95.982	19.382	35
SEWCT	spokane	influent	storm		9/9/98	7.84	1.96	4.809	1.036	0.0928	67.297	314.852	334
SICOM2	spokane	influent	storm		9/9/98	7.84	1.74	4.755	0.309	0.0758	70.240	256.773	214
SICOM3	spokane	influent	storm		9/9/98	13.28	2.38	5.458	0.371	0.0773	90.841	550.227	1386
SICOM1	spokane	influent	storm		9/16/98	5.88	2.40	4.701	0.464	0.0309	70.142	232.318	156
SICOM3	spokane	deposition	deposition box		9/16/98								348
SDEPOBOX	spokane	dead zone	water column	bottom	9/16/98	1.09	0.22	1.362	0.028	0.0031	75.782	30.568	10
SDWCB	spokane	dead zone	water column	top	9/16/98	1.21	0.34	1.113	0.056	0.0031	66.218	33.625	15
SDWCT	spokane	effluent	water column	bottom	9/16/98	1.30	0.22	2.183	0.087	0.0170	100.553	33.625	47
SEWCB	spokane	effluent	water column	top	9/16/98	1.30	0.22	1.643	0.059	0.0077	79.952	24.455	11
SEWCT	spokane	influent	water column	top	9/16/98	1.09	0.22	2.875	0.099	0.0634	108.891	30.568	12
SIWCT	spokane	influent	storm		9/16/98	6.75	2.62	4.809	0.603	0.0062	85.592	293.454	218
SICOM2	spokane	influent	storm		9/16/98	5.66	1.96	6.160	0.712	0.0077	113.551	262.886	282
SICOM1	spokane	reactor 3	batch		9/16/98	2.07	0.55	0.156	0.111	0.0186	116.003	61.136	24
SREACT3	spokane	reactor 2	batch		9/16/98	1.85	0.43	0.203	0.235	0.1036	125.568	73.364	7

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SREACT2	spokane	reactor 1	batch		9/16/98	3.38	0.43	0.117	0.619	0.0077	127.775	97.818	74
SREACT1	spokane	dead zone	interstitial		9/16/98	1.09	0.34	1.502	0.148	0.1346	99.817	39.739	
SDSTIT	spokane	effluent	interstitial		9/16/98	1.30	0.11	1.967	0.674	0.3960	187.616	24.455	
SESTIT	spokane	influent	interstitial		9/16/98	0.76	0.11	2.432	0.087	0.0866	105.703	30.568	
SISTIT	spokane	influent	water column	bottom	9/16/98	1.09	0.11	3.134	0.142	0.0835	117.965	27.511	31
SIWCB	vancouver	effluent	storm		9/18/98	3.05	0.87	0.971	0.093	0.0077	12.164	69.135	37
VECOM2	vancouver	effluent	storm		9/18/98	6.86	2.94	0.716	0.418	0.1933	30.019	111.933	96
VECOM1	vancouver	effluent	storm		9/18/98	2.83	0.87	0.895	0.124	0.0093	9.810	62.551	34
VECOM3	vancouver	effluent	storm		9/18/98	3.60	0.64	0.716	0.108	0.0093	11.772	75.720	50
VECOM4	vancouver	effluent	storm		9/18/98	3.17	0.32	0.778	0.093	0.0077	10.202	69.135	50
VECOM5	vancouver	effluent	storm		9/18/98	2.19	0.32	0.651	0.093	0.0062	9.614	49.382	37
VECOM6	vancouver	effluent	storm		9/18/98	1.96	0.32	0.566	0.170	0.0077	9.418	42.798	22
VECOM7	vancouver	effluent	storm		9/18/98	1.21	0.43	0.495	0.031	0.0062	8.240	39.506	21
VECOM8	vancouver	effluent	water column	top	9/27/98	4.03	0.87	1.783	0.124	0.0093	19.031	92.180	28
VEWCT	vancouver	effluent	water column	bottom	9/27/98	4.26	1.09	1.469	0.124	0.0124	21.778	95.472	48
VEWCB	vancouver	influent	water column	top	9/27/98	6.00	0.87	1.793	0.402	0.0140	21.190	125.102	70
VIWCT	vancouver	dead zone	water column	top	9/27/98	5.13	1.09	1.246	0.201	0.0310	22.171	121.810	52
VDWCT	vancouver	dead zone	water column	bottom	9/27/98	4.15	0.98	0.527	0.170	0.0171	24.133	125.102	70.67
VDWCB	vancouver	influent	interstitial		9/27/98	2.51	0.22	1.293	0.068	0.0093	86.524	65.843	
VISTIT	vancouver	influent	water column	bottom	9/27/98	7.17	0.98	0.527	0.464	0.0248	25.506	368.721	598
VIWCB	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	36
VECOM8	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	134
VECOM1	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	134

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VECOM2	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	147
VECOM3	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	120
VECOM4	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	82
VECOM5	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	77
VECOM6	vancouver	effluent	storm		10/3/98	not run	not run	not run	not run	not run	not run	not run	54
VECOM7	spokane	effluent	storm		10/9/98	10.68	4.15	not run	0.665	not run	not run	347.795	392
SECOM1	spokane	effluent	storm		10/9/98	6.56	2.61	not run	0.229	not run	not run	115.932	19
SECOM3	spokane	effluent	storm		10/9/98	9.58	2.18	not run	1.624	not run	not run	457.102	764
SECOM4	spokane	effluent	storm		10/9/98	5.66	2.18	not run	0.192	not run	not run	112.619	25
SECOM5	spokane	influent	storm		10/9/98	6.98	3.28	not run	0.161	not run	not run	129.181	15
SICOM7	spokane	influent	storm		10/9/98	7.62	3.28	not run	0.108	not run	not run	221.926	196
SICOM8	spokane	influent	storm		10/9/98	6.98	2.83	not run	0.046	not run	not run	161.316	57
SICOM5	spokane	influent	storm		10/9/98	9.16	2.18	not run	1.995	not run	not run	411.519	1068
SICOM1	spokane	influent	storm		10/9/98	7.62	2.64	not run	0.479	not run	not run	181.068	120
SICOM2	spokane	influent	storm		10/9/98	6.11	2.64	not run	0.118	not run	not run	207.406	70
SICOM4	spokane	influent	storm		10/9/98	5.88	2.83	not run	0.186	not run	not run	128.394	12
SICOM6	spokane	effluent	storm		10/9/98	16.56	1.09	not run	1.856	not run	not run	552.401	2148
SECOM8	spokane	effluent	storm		10/9/98	3.70	0.45	not run	0.229	not run	not run	49.685	20
SECOM7	spokane	influent	storm		10/9/98	6.56	2.41	not run	0.495	not run	not run	187.653	114
SICOM3	spokane	effluent	storm		10/9/98	15.69	1.74	not run	1.640	not run	not run	478.748	1544
SECOM6	spokane	influent	storm		10/13/98	3.17	3.70	3.802	0.266	0.0541	106.275	125.102	109.33
SICOM2	spokane	influent	storm		10/13/98	1.42	0.45	4.742	0.148	0.0913	120.663	16.461	10
SICOM1	spokane	influent	storm		10/13/98	2.19	3.50	4.147	0.235	0.0557	105.948	75.720	53.33
SICOM3	spokane	effluent	storm		10/13/98	0.98	0.0	3.033	0.012	0.0031	102.024	6.584	10
SECOM1	spokane	effluent	storm		10/13/98	0.98	0.22	3.332	0.019	0.0046	103.659	9.876	9
SECOM3	spokane	effluent	storm		10/13/98	1.42	0.22	3.204	0.436	0.0201	105.294	26.337	7
SECOM2	vancouver	influent	storm		10/27/98	6.56	2.61		0.665	0.0046	14.911	221.926	180
VICOM	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	55.5
VECOM1	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	51.5
VECOM8	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	22.5
VECOM3	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	46
VECOM2	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	42

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VECOM7	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	82.5
VECOM4	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	53.5
VECOM5	vancouver	effluent	storm		11/4/98	not run	not run	not run	not run	not run	not run	not run	53
VECOM6	spokane	influent	storm		11/5/98	2.83	0.98	2.971	0.263	0.0217	52.974	145.743	160
SICOM1	spokane	influent	storm		11/5/98	3.92	0.76	1.839	0.217	0.0124	68.081	235.176	236
SICOM2	spokane	influent	storm		11/5/98	2.83	0.66	2.773	0.433	0.0263	95.942	182.178	126
SICOM3	spokane	effluent	storm		11/5/98	1.96	0.32	4.188	0.056	0.0217	81.815	13.249	9
SECOM1	spokane	effluent	storm		11/5/98	1.85	0.38	3.848	0.077	0.0325	122.821	13.249	11
SECOM2	spokane	effluent	water column	bottom	11/11/98	1.20	0.29	2.349	0.148	0.0077	121.252	160.085	33.5
SEWCB	spokane	reactor 2	batch		11/11/98	1.75	0.29	0.015	0.071	0.0046	99.277	105.511	4.5
SREACT2	spokane	dead zone	interstitial		11/11/98	0.53	0.21	1.249	0.105	0.0232	103.397	32.745	
SDSTIT	spokane	influent	interstitial		11/11/98	1.42	0.44	1.584	0.687	0.1872	171.086	69.128	
SESTIT	spokane	influent	water column	bottom	11/11/98	0.77	0.11	3.007	0.028	0.0077	119.093	7.277	6.5
SIWCB	spokane	reactor 3	batch		11/11/98	1.75	0.44	0.027	0.040	0.0015	92.999	25.468	5
SREACT3	spokane	reactor 1	batch		11/11/98	1.96	0.29	0.004	0.334	0.0046	97.904	152.808	58
SREACT1	spokane	dead zone	water column	bottom	11/11/98	1.64	0.21	2.654	0.053	0.0015	108.499	36.383	17
SDWCB	spokane	dead zone	water column	top	11/11/98	1.53	0.21	2.619	0.040	0.0015	109.087	10.915	5
SDWCT	spokane	effluent	water column	top	11/11/98	1.53	0.22	3.085	0.148	0.0077	119.290	21.830	14
SEWCT	spokane	influent	water column	top	11/11/98	1.20	0.11	3.240	0.136	0.0155	124.979	0.000	7.5
SIWCT	spokane	influent	interstitial		11/11/98			2.523	0.118	0.0402	66.708	141.894	
SISTIT	vancouver	influent	storm		11/19/98	insuff sample	1.30	1.712	0.371	0.011	17.658	158.992	216
VICOM9	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	37.778
VECOM8	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	17.5

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VECOM6	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	48
VECOM7	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	27
VECOM5	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	39
VECOM4	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	43.6
VECOM3	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	21
VECOM2	vancouver	effluent	storm		11/19/98	not run	not run	not run	not run	not run	not run	not run	28.5
VECOM1	vancouver	influent	storm		11/19/98	insuff sample	1.09	1.200	0.371	0.009	22.759	268.299	216
VICOM4	vancouver	influent	storm		11/19/98	insuff sample	1.21	0.665	0.309	0.009	13.342	218.298	150
VICOM12	vancouver	influent	storm		11/19/98	insuff sample	1.21	0.766	0.278	0.009	367.679	163.723	136
VICOM11	vancouver	influent	water column	top	11/19/98	1.08	0.22	1.942	0.093	0.011	60.822	129.181	16
VIWCT	vancouver	influent	water column	bottom	11/19/98	1.51	0.32	2.028	0.201	0.012	67.493	125.869	64
VIWCB	vancouver	influent	storm		11/19/98	insuff sample	0.87	1.591	0.340	0.014	25.114	43.060	188
VICOM3	vancouver	influent	storm		11/19/98	insuff sample	0.87	1.865	0.309	0.012	37.278	99.370	100
VICOM1	vancouver	influent	storm		11/19/98	insuff sample	2.07	insuff sample	0.433	0.014	14.519	119.244	252
VICOM7	vancouver	dead zone	water column	bottom	11/19/98	8.24	1.42	0.791	0.526	0.008	23.544	178.866	384
VDWCB	vancouver	dead zone	water column	top	11/19/98	2.49	1.09	0.679	0.124	0.008	21.190	129.181	21
VDWCT	vancouver	effluent	water column	bottom	11/19/98	1.96	0.98	0.702	0.099	0.003	12.753	142.430	16
VEWCB	vancouver	influent	storm		11/19/98	insuff sample	1.42	0.853	0.371	0.014	17.658	72.871	244
VICOM8	vancouver	effluent	water column	top	11/19/98	3.26	0.87	0.460	0.074	0.006	13.538	109.307	71

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VEWCT	vancouver	influent	storm		11/19/98	insuff sample	1.53	1.215	0.495	0.009	14.519	99.370	200
VICOM10	vancouver	influent	storm		11/19/98	insuff sample	0.87	1.721	0.371	0.009	39.632	211.989	140
VICOM2	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	224
SICOM1	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	128
SICOM2	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	193
SICOM3	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	41.333
SECOM8	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	184
SICOM5	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	14
SECOM1	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	408
SECOM3	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	143.333
SECOM4	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	56.667
SICOM8	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	173.333
SICOM7	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	150.667
SICOM6	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	34.5
SECOM7	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	172
SECOM5	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	77
SECOM2	spokane	influent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	109
SICOM4	spokane	effluent	storm		11/20/98	not run	not run	not run	not run	not run	not run	not run	47.6
SECOM6	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	130
SICOM3	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	34.8
SECOM3	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	184.6
SICOM2	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	112.6
SICOM4	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	118.6
SICOM5	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	106.6
SICOM6	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	124.6
SICOM7	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	110
SICOM8	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	16.8
SECOM2	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	25.2
SECOM4	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	20.8
SECOM5	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	25.2

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SECOM6	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	8.4
SECOM8	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	30.8
SECOM7	spokane	influent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	169.3
SICOM1	spokane	effluent	storm		11/25/98	not run	not run	not run	not run	not run	not run	not run	13.2
SECOM1	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	10.4
VECOM4	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	12.4
VECOM1	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	129.2
VICOM1	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	90.8
VICOM2	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	84.8
VICOM3	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	67.6
VICOM4	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	68
VICOM5	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	43.6
VICOM6	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	39.2
VICOM7	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	35.6
VICOM8	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	31.2
VICOM9	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	15.6
VICOM10	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	11.2
VECOM6	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	16.4
VICOM12	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	10.8
VECOM2	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	6
VECOM3	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	11.6
VECOM5	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	10
VECOM7	vancouver	effluent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	9.6
VECOM8	vancouver	influent	storm		11/26/98	not run	not run	not run	not run	not run	not run	not run	20
VICOM11	spokane	effluent	storm		12/7/98	2.38	0.22	2.299	0.118	0.1284	90.743	9.821	20.8
SECOM3	spokane	effluent	storm		12/7/98	2.61	0.16	1.339	0.080	0.0402	90.252	39.282	30.4
SECOM2	spokane	effluent	storm		12/7/98	1.51	0.16	2.271	0.019	0.0681	91.724	81.838	25.6
SECOM1	spokane	influent	storm		12/7/98	3.48	0.54	2.047	0.099	0.1005	90.007	78.564	21
SICOM3	spokane	influent	storm		12/7/98	2.83	0.32	2.103	0.084	0.0990	87.800	65.470	92
SICOM2	spokane	influent	storm		12/7/98	5.44	0.54	1.283	0.144	0.0804	92.950	130.941	116.67
SICOM1	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	92
VICOM6	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	67

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VICOM11	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	71
VICOM10	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	78
VICOM9	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	92
VICOM7	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	53.3
VICOM5	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	109.3
VICOM4	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	126
VICOM3	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	134
VICOM2	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	134
VICOM1	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	43.6
VICOM12	vancouver	influent	storm		1/9/99	not run	not run	not run	not run	not run	not run	not run	80
VICOM8	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	580
VICOM2	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	636
VICOM5	spokane	reactor 2	batch		1/12/99	0.64	0.14	0.068	0.028	0.0046	19.865	15.926	12
SREACT2	spokane	reactor 1	batch		1/12/99	0.76	0.14	0.005	0.037	0.0015	12.508	19.111	8
SREACT1	spokane	effluent	water column	bottom	1/12/99	1.30	0.21	2.637	0.365	0.1191	115.758	66.888	62
SEWCB	spokane	effluent	water column	top	1/12/99	1.30	0.14	2.853	0.402	0.1253	113.796	47.777	34
SEWCT	spokane	influent	water column	bottom	1/12/99	1.96	0.43	2.866	0.588	0.0990	107.665	63.703	103
SIWCB	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	676
VICOM4	spokane	influent	interstitial		1/12/99			2.743				25.481	
SISTIT	spokane	effluent	interstitial		1/12/99			1.553				28.666	
SESTIT	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	580
VICOM1	spokane	reactor 3	batch		1/12/99	1.08	0.21	0.023	0.031	0.0062	16.677	9.555	13
SREACT3	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	618
VICOM3	spokane	influent	water column	top	1/12/99	0.98	0.21	3.191	0.247	0.1346	109.627	22.296	18
SIWCT	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	540
VICOM6	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	436

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VICOM7	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	406
VICOM8	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	396
VICOM9	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	374
VICOM10	vancouver	influent	storm		1/12/99	not run	not run	not run	not run	not run	not run	not run	354
VICOM11	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	15.6
SECOM3	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	12.8
SECOM5	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	7.2
SECOM7	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	13.2
SECOM6	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	43.6
SECOM1	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	13.6
SECOM2	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	18
SECOM4	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	945
SICOM2	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	343.5
SICOM8	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	1620
SICOM1	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	333
SICOM4	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	505
SICOM5	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	498
SICOM6	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	379
SICOM7	spokane	effluent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	19.6
SECOM8	spokane	influent	storm		1/16/99	not run	not run	not run	not run	not run	not run	not run	325
SICOM3	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	1.319	0.130	0.008	12.263	36.098	70
VICOM3	vancouver	dead zone	water column	bottom	1/17/99	1.42	0.43	0.155	0.210	0.008	10.055	62.197	114
VDWCB	vancouver	effluent	storm		1/17/99	1.30	0.22	0.584	0.136	0.002	11.527	10.829	63
VECOM8	vancouver	effluent	storm		1/17/99	1.19	0.22	0.285	0.136	0.012	11.772	7.220	58
VECOM7	vancouver	effluent	storm		1/17/99	1.19	0.34	0.306	0.124	0.002	12.263	7.220	52
VECOM6	vancouver	effluent	storm		1/17/99	1.08	0.33	0.296	0.124	0.006	10.791	18.049	64
VECOM5	vancouver	effluent	storm		1/17/99	1.19	0.33	0.817	0.105	0.005	9.320	0.0	59
VECOM4	vancouver	influent	water column	top	1/17/99	1.42	0.22	0.090	0.297	0.008	7.358	137.172	153
VIWCT	vancouver	influent	water column	bottom	1/17/99	2.28	0.22	0.122	0.266	0.006	9.810	324.880	136

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VIWCB	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	1.884	0.136	0.006	10.055	36.098	70
VICOM5	vancouver	dead zone	interstitial		1/17/99	2.49	1.31	2.664	0.390	0.275	25.751	43.317	
VDSTIT	vancouver	dead zone	water column	top	1/17/99	1.19	0.29	0.167	0.272	0.003	10.301	93.854	92
VDWCT	vancouver	effluent	water column	top	1/17/99	1.30	0.29	0.788	0.148	0.003	8.584	144.391	63
VEWCT	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	0.227	0.142	0.009	12.263	21.659	53
VICOM1	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	0.217	0.087	0.008	12.263	18.049	48
VICOM2	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	1.997	0.124	0.006	11.772	18.049	60
VICOM4	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	1.470	0.148	0.006	11.527	36.098	83
VICOM6	vancouver	influent	storm		1/17/99	insuff vol	insuff vol	4.070	0.192	0.002	12.753	50.537	83
VICOM7	vancouver	effluent	storm		1/17/99	1.19	0.33	0.289	0.111	0.003	12.753	3.610	58
VECOM3	vancouver	effluent	storm		1/17/99	1.19	0.33	0.289	0.217	0.003	13.244	10.829	53
VECOM2	vancouver	effluent	storm		1/17/99	1.51	0.49	0.370	0.111	0.0	11.527	7.220	60
VECOM1	vancouver	effluent	water column	bottom	1/17/99	1.30	0.22	0.177	0.217	0.005	11.282	93.854	86
VEWCB	vancouver	influent	storm		2/2/99	not run	not run	not run	not run	not run	not run	not run	208
VICOM	vancouver	effluent	storm		2/2/99	not run	not run	not run	not run	not run	not run	not run	13.2
VECOM	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	14
SECOM5	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	13.33
SECOM8	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	10
SECOM7	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	16.8
SECOM4	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	8
SECOM3	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	3.5
SECOM2	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	7
SECOM1	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	1224
SICOM8	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	1360
SICOM7	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	2000
SICOM6	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	2124
SICOM5	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	2792
SICOM4	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	2108

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SICOM3	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	1920
SICOM2	spokane	influent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	1588
SICOM1	spokane	effluent	storm		2/16/99	not run	not run	not run	not run	not run	not run	not run	14
SECOM6	vancouver	influent	storm		2/22/99	1.42	0.34	2.775	0.483	0.0294	2.207	147.308	104
VICOM	vancouver	effluent	storm		2/23/99	1.30	0.41	3.846	0.136	0.0093	8.584	29.462	29
VECOM1	vancouver	effluent	storm		2/23/99	1.51	0.45	3.709	0.118	0.0077	11.772	39.282	33
VECOM3	vancouver	effluent	storm		2/23/99	1.42	0.64	3.984	0.139	0.0062	11.772	36.009	47
VECOM2	spokane	influent	water column	top	3/15/99	1.3845	0.6643	4.252	0.161	0.116	129.265	45.856	12.4
SIWCT	spokane	influent	water column	bottom	3/15/99	1.2738	0.8857	4.570	0.130	0.116	128.773	insuff sample	11.6
SIWCB	spokane	effluent	water column	top	3/15/99	1.3845	0.6089	4.122	0.158	0.113	127.299	18.342	7.6
SEWCT	spokane	effluent	water column	bottom	3/15/99	1.3845	0.8304	4.498	0.176	0.118	128.282	21.399	8.4
SEWCB	spokane	deposition	deposition box		3/15/99								358
SDEPOBOX	spokane	dead zone	water column	top	3/15/99	1.3845	0.7750	3.182	0.155	0.104	126.807	42.799	4.8
SDWCT	spokane	dead zone	water column	bottom	3/15/99	1.8274	1.6054	4.093	0.254	0.105	128.036	67.255	42
SDWCB	spokane	reactor 1	batch		3/15/99	1.3845	0.9411	0.0	0.056	0.012	68.319	6.258	5.2
SREACT1	spokane	reactor 2	batch		3/15/99	1.4952	1.1072	0.020	0.034	0.006	78.640	9.387	3.5
SREACT2	spokane	reactor 3	batch		3/15/99	1.3292	0.6089	0.001	0.031	0.005	66.598	18.775	1.6
SREACT3	spokane	influent	storm		3/25/99	5.2550	1.6608	2.030	1.299	0.1222	129.510	351.561	808
SICOM3	spokane	effluent	storm		3/25/99	0.4993	0.7750	8.349	0.142	0.0789	112.799	39.742	11.5
SECOM3	spokane	influent	storm		3/25/99	4.8168	2.2143	4.405	1.268	0.1129	146.221	339.333	607
SICOM2	spokane	influent	storm		3/25/99	3.4328	1.6608	5.614	1.052	0.1067	154.331	238.450	472
SICOM1	spokane	effluent	storm		3/25/99	0.8309	0.8857	4.362	0.148	0.0974	128.282	0.0	26.67

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
SECOM7	spokane	effluent	storm		3/25/99	0.5542	0.6643	4.678	0.142	0.0804	129.510	3.057	22.5
SECOM6	spokane	effluent	storm		3/25/99	1.1077	0.7750	4.549	0.127	0.0789	127.544	15.285	12.5
SECOM4	spokane	effluent	storm		3/25/99	2.6669	0.7750	7.025	0.148	0.0820	120.418	15.285	8.5
SECOM2	spokane	effluent	storm		3/25/99	1.4399	0.8857	7.802	0.148	0.0974	120.418	15.285	17.5
SECOM1	spokane	influent	storm		3/25/99	0.8309	1.4393	3.930	0.176	0.1408	124.350	18.342	28
SICOM8	spokane	influent	storm		3/25/99	1.0524	0.9965	4.088	0.198	0.1067	110.588	15.285	35.5
SICOM7	spokane	influent	storm		3/25/99	1.4399	1.1072	4.275	0.229	0.1191	112.799	18.342	63
SICOM6	spokane	influent	storm		3/25/99	1.3851	1.9929	3.829	0.272	0.1160	113.537	36.685	56
SICOM5	spokane	influent	storm		3/25/99	1.8274	1.2179	3.671	0.650	0.1052	110.342	137.567	326
SICOM4	spokane	effluent	storm		3/25/99	0.9417	1.1072	4.376	0.133	0.0897	128.036	3.057	33
SECOM5	vancouver	influent	water column	top	3/28/99	1.6060	1.0794	0.692	0.161	0.0046	13.271	36.685	45
VIWCT	vancouver	dead zone	water column	bottom	3/28/99	2.1595	1.2177	0.692	0.167	0.0139	12.288	42.799	48
VDWCB	vancouver	influent	storm		3/28/99	not run	not run	0.976	not run	0.0155	13.271	24.456	22
VICOM2	vancouver	influent	storm		3/28/99	not run	not run	0.623	not run	0.0046	11.550	42.799	70
VICOM1	vancouver	dead zone	water column	top	3/28/99	2.6024	1.2177	0.699	0.167	0.0062	12.533	39.742	94
VDWCT	vancouver	effluent	water column	bottom	3/28/99	1.8828	1.2731	0.663	0.155	0.0031	11.550	42.799	50
VEWCB	vancouver	influent	water column	bottom	3/28/99	1.8274	1.2731	0.677	0.148	0.0046	12.533	27.513	41
VIWCB	vancouver	effluent	water column	top	3/28/99	1.4952	1.1901	0.663	0.130	0.0031	12.533	27.513	38
VEWCT	spokane	influent	storm		4/3/99	4.0971	1.4390	2.978	0.210	0.0464	85.521	67.255	72
SICOM1	spokane	effluent	storm		4/3/99	0.8301	0.5533	3.817	0.229	0.0974	113.045	0.0	16
SECOM3	spokane	effluent	storm		4/3/99	0.9962	0.6364	4.195	0.186	0.1052	119.435	3.057	5
SECOM2	spokane	effluent	storm		4/3/99		0.7194	5.942	0.189	0.1114	120.418	27.513	10
SECOM1	spokane	influent	storm		4/3/99	1.2738	0.8301	2.908	0.155	0.0990	78.640	45.856	30
SICOM3	spokane	influent	storm		4/3/99	1.3292	1.1069	3.076	0.148	0.0974	71.759	48.913	38
SICOM2	vancouver	influent	storm		4/21/99	4.1525	2.7129	1.342	0.294	0.0062	14.991	193.989	87
VICOM2	vancouver	influent	storm		4/21/99	2.9346	2.2146	5.928	0.148	0.0186	ACIDIC	175.216	39

sample ID	sample location	pond location	sample type	sample position	sample date	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	TP (mg/L)	ortho-P (mg/L)	Alkalinity (mg/L)	COD (mg/L)	TSS (mg/L)
VICOM3	vancouver	influent	storm		4/21/99	6.3668	3.3772	1.650	0.402	0.0062	16.711	322.272	131
VICOM1	vancouver	influent	storm		4/27/99	4.7564	0.8851	1.349	2.017	1.0118	25.558		24
VICOM3	vancouver	influent	storm		4/27/99	7.9879	3.7056	1.855	0.841	0.0424	18.186	190.860	46
VICOM2	vancouver	influent	storm		4/27/99	8.9586	4.9223	1.181	0.520	0.0833	18.186	234.664	99
VICOM1	spokane	influent	water column	top	5/12/99	2.1010	1.6041	3.436	0.173	0.0294	123.927	96.994	12
SIWCT	spokane	reactor	batch		5/12/99	1.8245	0.9404	0.098	0.043	0.0093	98.550		6
SREACT3	spokane	reactor	batch		5/12/99	2.3222	1.3829	0.061	0.121	0.0247	85.985	34.417	9
SREACT2	spokane	reactor	batch		5/12/99	2.1010	1.4935	0.031	0.155	0.0031	98.057	40.675	17
SREACT1	spokane	dead zone	water column	bottom	5/12/99	2.7646	1.3829	3.375	0.204	0.0015	118.753	56.319	62
SDWCB	spokane	dead zone	water column	top	5/12/99	2.0457	0.9404	2.963	0.139	0.0093	119.738	50.062	24
SDWCT	spokane	effluent	water column	bottom	5/12/99	1.7138	0.8298	2.993	0.173	0.0046	122.941	43.804	38
SEWCB	spokane	influent	water column	bottom	5/12/99	2.4481	0.9957	3.253	0.133	0.0062	142.158	34.417	11
SIWCB	spokane	effluent	water column	top	5/12/99	2.0468	1.1617	3.009	0.118	0.0046	125.159	37.546	13
SEWCT	vancouver	effluent	water column	bottom	5/21/99	0.8846	1.6041	0.367	0.031	0.019	5.913	28.160	11
VEWCB	vancouver	influent	water column	top	5/21/99	1.6035	1.3829	0.337	0.124	0.026	13.304	62.577	42
VIWCT	vancouver	effluent	water column	top	5/21/99	0.9399	1.2723	0.385	0.025	0.005	12.072	21.902	13
VEWCT	vancouver	dead zone	water column	top	5/21/99	1.4376	1.6041	0.313	0.037	0.006	11.087	37.546	11

10 APPENDIX E - SPOKANE POND ALGAE DATA

Table 19. Estimate of total algal biomass in the pond, and the measured metals concentrations contained in the algae.

July 11, 1997						Total algal biomass = 200 kg			
location	S1	S2	S3	S4	S5	S6	S7	S8	S9
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Calcium	105343	60022	64830	31574	60072	45398	96834	**	**
Magnesium	12891	10819	16034	16566	16654	8986	15441	**	**
Iron	5501	13370	3913	6532	4574	5019	2092	**	**
Copper	19	40	14	20	20	18	10	**	**
Lead	29	74	28	41	33	37	13	**	**
Zinc	196	369	244	322	233	221	148	**	**
Cadmium	nd	nd	nd	0.22	nd	nd	0.05	**	**

May 9, 1998						Total algal biomass not recorded			
Calcium	**	122137	**	106586	**	**	**	180967	**
Magnesium	**	4803	**	4278	**	**	**	4879	**
Iron	**	6699	**	3381	**	**	**	13876	**
Copper	**	29	**	13	**	**	**	20	**
Lead	**	32	**	15	**	**	**	15	**
Zinc	**	182	**	109	**	**	**	111	**
Cadmium	**	nd	**	nd	**	**	**	nd	**

July 16, 1998						Total algal biomass = 650 kg			
Calcium	8257	8978	**	8728	**	8313	**	8427	8635
Magnesium	9107	17673	**	16915	**	6105	**	12758	7918
Iron	3864	493	**	423	**	683	**	536	1296
Copper	18	8	**	9	**	9	**	13	11
Lead	26	8	**	4	**	7	**	5	9
Zinc	142	97	**	58	**	65	**	68	75
Cadmium	1	1	**	1	**	nd	**	nd	nd

September 16, 1998						Total algal biomass = 650 kg			
Calcium	8862	9001	9755	9430	9271	9407	9218	9295	9922
Magnesium	25007	16238	16080	25323	20606	23391	19086	15623	20832
Iron	506	219	798	459	437	1253	441	961	2762
Copper	9	5	7	11	5	7	6	8	11
Lead	5	2	6	7	3	8	2	8	22
Zinc	58	31	37	45	33	42	30	45	109
Cadmium	1	nd	1	2	nd	nd	nd	2	nd

** - No algae present in this location at time of sample collection.

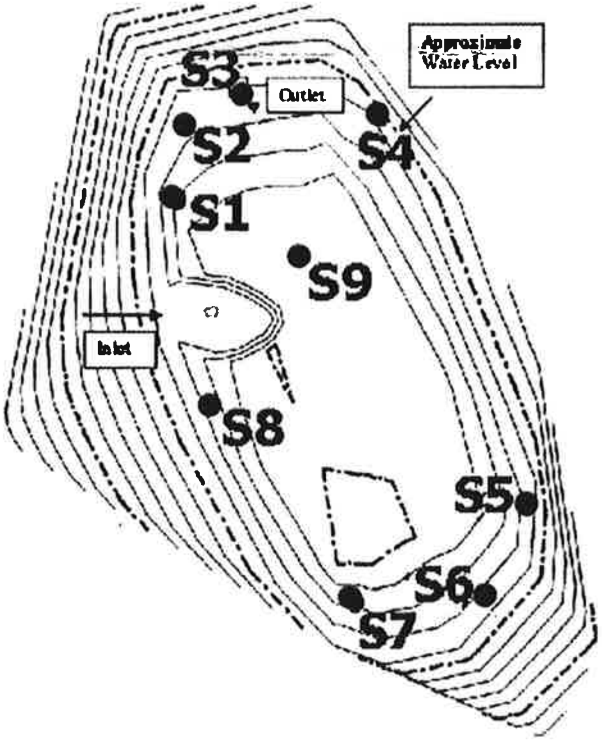


Figure 29. Location of inlet, outlet, and algae sampling locations for the Spokane wet pond.

Table 20. Measured metals concentration found in the roots as compared with the metals concentrations found in the bloom of algae from Spokane wet pond.

Sample Location	S8	**Algae bloom near S8**	**Algae roots near S8**
Metals	mg/kg	mg/kg	mg/kg
Calcium	9295	22282	6578
Magnesium	15623	9232	8794
Iron	961	404	497
Copper	8	5	6
Lead	8	27	29
Zinc	45	4	2
Cadmium	2	0	0

11 APPENDIX F - DSS USERS MANUAL

INSTALLATION AND OPERATING GUIDE

HIGHWAY RUNOFF WET POND DESIGN DECISION SUPPORT SYSTEM

For NCHRP Project 25-12

Department of Civil and Environmental Engineering

Washington State University
Pullman, Washington

March 11, 2002

TABLE OF CONTENTS

1 INTRODUCTION

This version of the wet pond design decision support system (DSS) is capable of predicting suspended solids, metal, and nutrient concentrations exiting a wet pond. The DSS can also be used to develop a runoff hydrograph that can be used as inflow to the wet pond. It can estimate required pond volume given desired pollutant discharge concentrations through a user-initiated iterative process. In either case, the user is required to enter input parameter values (flow, TSS concentration, particle size distribution, etc.) or use default values supplied in the DSS (default values can be changed as the user progresses through the program).

Details of the DSS predictive methods are presented in the final report. In brief, the model treats a wet pond as a completely mixed reactor and dead volume is accounted for by a user-entered “effective volume” fraction. Estimates of dead volume and effective volume were developed from inert tracer experiments that were performed in field and scale model tests. Effluent suspended solids concentration prediction incorporates discrete particle settling theory (Stokes Law) while effluent metal (Cd, Cu, Pb, and Zn) concentration is determined by assuming that the metals partition onto particulate matter and are removed during sedimentation. Metal partition coefficients were determined from storm water samples collected during storm events in Vancouver and Spokane, Washington. The model assumes that the soluble fraction of metals remains constant and is not altered within the pond. The DSS calculates effluent nutrient (total Kjeldahl nitrogen, ammonia, nitrate, total phosphorus, and orthophosphate) concentration by applying first order kinetics where the reaction rate order and constants were determined using in-pond reactor data collected in the Spokane pond. Again, default values for the metal partition coefficients and nutrient reaction rate constants can be used or the user can change the default values at any time during a DSS run.

2 INSTALLATION OF SOFTWARE

Although the DSS may be run from the supplied floppy disk *if your system has the appropriate operating system files*, it is recommended that the program file (nchrp.exe) on the supplied floppy disk be copied to your hard drive prior to executing the program. The DSS has been tested on Windows 95, Windows 98, Windows NT-service pack 4.0 and 6.0, and Windows 2000. Windows 95 requires a dll file (msvbvm60.dll) and Windows 2000 requires an ocx file (comdlg32.ocx). These files have been supplied on the enclosed floppy disks. Other operating system files may be required depending on your particular version of the Windows operating system. If after the DSS and required dll or ocx files are loaded and an error message is received when attempting to run the program, please call (509) 335 – 2147 or email yonge@wsu.edu and indicate what the error message states. Every effort will be made to resolve the problem.

2.1 Installation Procedure

The installation of the DSS is straightforward and only requires that files be copied from the supplied floppy disk to you hard drive. For ease of finding the file after transfer, it is recommended that a folder (directory) with a descriptive name (e.g., DSS) be made on the hard drive and the DSS file (nchrp.exe) be place in that directory. If you are running Windows 95 or 2000, add the respective msvbvm60.dll or comdlg32.ocx to the directory.

3 DSS OPERATION

Go to the directory containing the DSS. Double click on the ncrhp.exe icon and the program should load the input screens one by one. Section 3.1, below, briefly summarizes the input screens that the user will encounter during the use of the DSS. Section 3.2 presents more detailed information on screens that require user input, describing the input parameters and defining the methods used for calculations. Finally, Section 4 presents a design example, showing individual screens as the user would see them with input parameters and DSS output.

3.1 Input Screen Summary

Screen – 1:

This is an introductory screen.

- Click on "Continue".

Screen – 2

This is an introductory screen.

- Click on "Accept" to move to the next input screen.

Screen – 3

The screen provides two choices for the input hydrograph. The SCS Triangular unit hydrograph and the "User Defined" unit hydrograph (see Section 3.2 for details).

- Select one of the choices.
- Click on "Continue" to move to the next screen.

Screen – 4

If the SCS triangular hydrograph is selected in the previous screen then this screen will appear. The user has to select a method to compute the overland flow.

- Select a method.
- Click on "Continue" to move to the next input screen.

Screen – 5

This screen will ask for a curve number and duration of the excess precipitation when the SCS triangular unit hydrograph is selected.

  - Enter the curve number in the appropriate box.
  - Enter duration of the excess precipitation in the appropriate box.

- Click on “Continue” to move to the next input screen.

Screen – 6

A hyetograph is a graph of rainfall intensity as a function of time. The model uses a one-ordinate hyetograph system for simplicity (i.e., an average constant value of rainfall over the time of excess rainfall).

- Enter the average precipitation value.

No input is needed at the first box of “constant duration time step” as the model will show the value in the screen.

- Click on “Next” button to complete entering precipitation value.
- Click “Continue” to move to the next screen.

Screen – 7

If the user selects “Federal Aviation Agency” (FAA) equation to compute overland flow, this screen needs to be completed. For further details, please consult section 3.2.

- Enter percent area of each type of ground cover.
- Click on “Continue” to move to the next screen.

Summation of all the areas entered must be 100%.

Screen – 8

This screen provides a summary of the unit hydrograph generated and allows the user to select flow that to be used in designing the wet pond.

- Select a method.
- Click on “Continue” to move to the next screen.

A design based on peak flow will result in a conservative approach to the design.

Screen – 9

- Select “default data”.
- Click on “Continue” to move to the next screen.

The next screen contains default data for modeling. The default data can be modified if site specific data is available.

Screen – 10

The screen requests data for pollutant modeling.

- Enter all the required data.
- Click on “Continue” to move to the next screen.

Please consult Section 3.2 for details of this screen.

Screen – 11

This screen requires information on the outflow weir that will be used as the outflow device for the wet pond being designed.

- Enter all the information.
- Click on "Continue" to move to the next screen.

Screen – 12

The information requested is for an existing pond or for a pond that is going to be designed. Design of a pond (determination of pond volume to achieve a desired discharge water quality) by DSS is an iterative process.

- Enter the values requested.
- Click on "Continue" to move to the next screen.

Screen – 13

This screen requires information on the chemicals to be modeled.

- Enter influent concentrations.
- Enter partitioning coefficients.
- Click on "Continue" to move to the next screen.

Screen – 14

This screen requires information on the nutrients and their first order decay rate. The model assumes first order kinetics.

- Enter pond influent (highway runoff) concentrations.
- Enter first order decay rates.
- Click on "Continue" to move to the next screen.

Screen – 15

This screen requires initial concentrations of the nutrients in the pond (those concentrations that existed prior to the storm event.

- Enter concentrations of the nutrients in the pond.
- Click on "Continue" to move to the next screen.

Screen – 16

The screen requires information on the number of data sets for the pond depth-area relationship (a data set contains water surface elevation, pond volume at that elevation, plan area at that elevation, and wetted surface area at that elevation), particle size distribution data pairs (a particle size and the corresponding percent smaller than, is one data pair) of the suspended solids entering the pond. The actual data set values are entered in Screen 17 and Screen 18.

- Enter how many data sets you have to define the depth-area relationship.
- Enter how many data sets you have to define the grain size distribution curves.

- Click on “Continue” to move to the next screen.

Screen – 17

Ponds usually have irregular geometry. The depth-area relationship must be provided for transport modeling.

- Enter the required information.
- Click on “Continue” to move to the next screen.

Screen – 18

This screen requires particle size distribution for the influent suspended solids.

- Enter the required values.
- Click on “Continue” to move to the next screen.

For more than four data sets (or pairs), the user should use the “Advance List” option.

Screen – 19

Site specific hydrograph data can be entered by using this screen.

- Enter the required data.
- Click on “Continue” to move on to the next screen.

The user can use the “Advance List” option to enter more than 4 data sets.

Screen – 20

This screen allows the user to enter the output file name. The output file contains elaborate data for plotting.

- Enter output file name.
- Click on “Continue” to start the modeling.

3.2 Detailed Description of the input Screens

Screen 3 – Determination of Storm Hydrograph

Select either “SCS Triangular Unit Hydrograph” or “user defined inflow hydrograph”. The SCS Triangular Unit Hydrograph method will enable the user to create a hydrograph based on standard SCS method. However, the user can use his/her own constant or variable flow through the second selection (“user defined”). Click “Continue” to proceed.

Screen 4 – Hydrograph creation by SCS method

The SCS triangular rainfall-runoff hydrograph, as shown in Figure 30, is used frequently for its simple design. The DSS will provide the user with the peak discharge (q_{pk}) after the input of the necessary parameters as defined below.

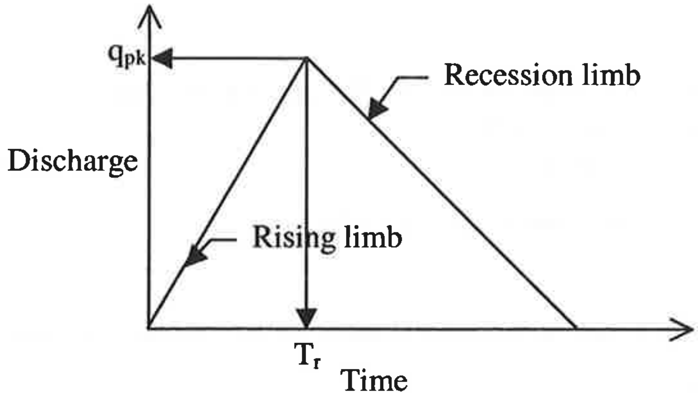


Figure 30. Elements of an SCS triangular unit hydrograph

The peak discharge, q_{pk} (ft^3/s), is given by the following equation:

$$q_{pk} = \frac{484 \cdot W_{eff} \cdot A_D}{T_r} \tag{B.1}$$

Where T_r is the time of rise (hr), W_{eff} is the effective rainfall (in), and A_D is the area of the drainage basin (mi^2).
The user must provide appropriate data in the defined units.

- The maximum distance from basin divide to outlet is the mainstream length of a watershed (mile) that is used to find time of concentration - a measure of watershed response time. This is basically the longest flow path for runoff to reach the outlet of the watershed, which is the inlet of the wet detention pond in this context.
- The basin drainage area is the total area of the watershed ($mile^2$) for which the wet pond is receiving runoff.
- Basin slope is the average grade of the terrain in (ft/ft) that also affects the time of concentration.
- The user then needs to check one box for calculating overland flow (surface runoff).
  Further data, as input to the next screen, may be needed based on the box checked. If no box is checked, the first option (SCS equation) becomes the default. For small watersheds, less than 2000 acres, the SCS equation provides good estimate of runoff. The user can use any method on a trial and error basis. The following information will be needed, as input to the next screen, depending upon the runoff hydrograph calculation method chosen.

- Composite curve number of the area if SCS method is chosen.
- Izzard runoff coefficient and average rainfall intensity for Izzard's equation.
- Rational method runoff coefficient if FAA method is chosen.
- Manning's roughness coefficient and average rainfall intensity for Ragan's equation.
- Kerby's runoff coefficient if Kerby's equation is chosen.

Screen 5 – Hydrograph creation by SCS method (Cont'd)

This screen asks for different values to be used in calculating overland flow based on the box checked by the user in the previous screen. Provide the values in specified units.

- **Composite curve number:** U.S. Soil Conservation Service has assigned curve numbers for various soils and land cover complexes. The user can find the curve numbers in McCuen (1998). The user can specify the duration of excess precipitation or click on "compute duration" to get a computed value.
- **Average rainfall intensity:** This is the average precipitation intensity in in/hr that occurs over the drainage area. Total volume of rainfall divided by the duration gives the intensity of rainfall.
- **Izzard runoff coefficient:** This coefficient is needed to compute runoff, if the user has selected the "Izzard's equation" in the previous screen. Click on "values" button to get an idea of the coefficients. Typical values of Izzard's coefficient are:

  Smooth asphalt = 0.007
  Concrete pavement = 0.012
  Tar and gravel pavements = 0.017
  Closely clipped sod = 0.046
  Dense bluegrass turf = 0.060

- **Rational runoff coefficient (C):** The Federal Aviation Agency Equation uses the runoff coefficient from the Rational method to compute the time of concentration. The value of runoff coefficient is a function of land use, cover condition, soil group, and basin slope. The coefficients can be found in McCuen (1998), Chow (1964), or in any hydrology textbook. However, if the user wants to compute the runoff coefficient by clicking on the "values" button, he/she will move to a new screen to compute the coefficient based on the data of land use of a non-homogeneous area.
- **Manning's roughness coefficient (n):** This is a coefficient based on channel conductance/resistance. The user can find values of Manning's n in Chow (1959), Dingman (2002), McCuen (1998), or in any hydraulic text.
- **Kerby runoff coefficient (N):** If the user selects the Kerby's method for computing overland flow in the previous screen, a coefficient is needed to compute the runoff. Typical values of the Kerby's N are:

  Smooth impervious surface = 0.02
  Bare packed soil = 0.10
  Poor grass = 0.20

Deciduous timberland = 0.60
Pasture or average grass = 0.40
Conifer timberland or dense grass = 0.80

- **Time of concentration:** This is defined as the time it takes for water to travel from the hydraulically most distant part of the watershed to the watershed outlet (wet pond inlet). The time of concentration will be computed by the DSS program.
- **Duration of excess precipitation:** This is the part of the rainfall that results in direct runoff. The model can compute this duration, when the user selects the "SCS Equation" for computing overland flow and clicks on "compute duration" button. However, the user can use a user-defined value for this input if data are available.

Screen 6 – Hyetograph creation

A hyetograph is a graph of rainfall intensity as a function of time. The model uses a one ordinate hyetograph system for simplicity (i.e., an average constant value of rainfall over the time of excess rainfall). The user only needs to enter that precipitation value in inches at the provided box. No input is needed at the first box of "constant duration time step" as the model will show the value in the screen. Click on "next" button to complete entering precipitation value.

Screen 7 – Runoff coefficient calculation

If the user selects "Federal Aviation Agency" (FAA) the FAA equation is used to compute overland flow, he/she will need to know the Rational Formula runoff coefficient (C). The FAA method requires the time of concentration, t_c in minutes, to be calculated by the following equation.

$$t_c = 1.8(1.1 - C)L^{0.5}S^{-0.333} \qquad \text{(B.2)}$$

Where C is the Rational Formula runoff coefficient, L is the flow length (ft), and S is the slope (ft/ft).

The coefficient C can be found in McCuen (1998), or any hydrology textbook. For a non-homogeneous watershed area, the user can click on "values" button to compute C. This screen helps to compute the coefficient based on different land use. The user only needs to enter percentage area of each type of land use in the appropriate boxes. Remember, the sum of the areas must be equal to 100 percent. Click on "continue" to compute the runoff coefficient.

Screen 8 – Hydrograph Summary

This screen summarizes the hydrograph created by SCS triangular unit hydrograph method. If the user has entered "1 inch" excess rainfall in screen 6 of "hyetograph creation", the result gives a unit hydrograph for that duration. Otherwise, it gives the total runoff hydrograph.

The primary objective of the DSS is to design a wet pond. The design of the pond mainly includes sizing (plan area and depth). Click on the box "Check if you want to size a pond" and select one of the three options in the drop down window. If the first option "Inflow hydrograph" is checked, the model takes into account the variable ordinate hydrograph that has been computed or entered by the user. If the second option "Peak discharge" is checked, the model assumes the peak discharge throughout the whole duration of hydrograph. Similarly, if third option "average discharge" is checked, the model assumes the average discharge throughout the hydrograph period. For a conservative approach, it is customary to use peak discharge. Click "Continue" to proceed.

Screen 9 – NCHRP Pollutant Removal Model

Select the "Use default data" or "Enter new data" and click "continue". It is recommended that the default data be used as many of the values are 'recommended' and will assist the user in progressing efficiently through the program. The default data is based on an existing wet pond near Spokane, Washington where extensive data were collected. The user may look at section 2.1 of the main report to find details about the pond. The pond design afforded by the DSS is based on a trial and error approach. A preliminary design of pond size and volume is made depending upon the inflow to the pond. A depth-area-volume relationship is prepared from the preliminary design. The model predicts the outflow hydrograph, effluent nutrient, TSS, and metal concentration. These numbers are checked with the regulatory limit. If regulatory requirements are not met, a bigger pond size will be assumed in the next trial. This procedure will be repeated until satisfactory results are obtained. Click "Continue" to proceed.

Screen 10 - Data Requests

The value entered for "how long do you want to run the model?" defines the simulation time for the model and the time period will normally be larger than the duration of the inflow that will "enter" the pond. It is recommended that the model should run for 24-48 hours for a 2-5 hour inflow hydrograph in the pond. The run time is chosen to be higher so that peak outflow can be computed, which is the most essential parameter to find percent TSS removal. The time step is needed for the numerical computational scheme. The recommended time step is 30-60 sec. A very small time step will cost the user a lengthy run time. However, if the model needs to be run for months or years, a bigger time step in hours or days should be used.

Provide the "average plan area" of the pond from preliminary design information. The "fraction of active volume" allows the user to account for pond dead volume. Based on field and scale model inert tracer testing, dead volume can occupy from 40% to 60% of the total pond volume. Elevation of the bottom of the pond is the elevation in ft above mean sea level. Enter "seepage rate" in in/hr of the pond. This rate is dependent on the soil type, the absence or presence of a clay lining or geomembrane, etc. If no data is available, it is a conservative approach to set the rate at "zero". Click "Continue" to proceed.

Screen 11 – Data Requests

The weir equation used in the model is

$$Q = C_w L H^n \tag{B.3}$$

where C_w is the weir coefficient, L is the length of the weir, and n is the exponent of the weir equation. Please see the section 2.7.1 of the main report for details about the weir equation. Values of C_w can range from 2.3 to 3.3, depending on the losses that occur at the weir (McCuen, 1998), but values from 2.6 to 3.1 are common for English units. The exponent "n" is always 1.5 unless the weir has been calibrated. It can vary 5-10% after calibration. Elevation of the top of the weir is the elevation in ft above mean sea level.

"Influent TSS" refers to the average value of total suspended solids concentration entering the pond. This value may be found from the literature, if available, or from direct measurement. Click "Continue" to proceed.

Screen 12 – Data Requests

The "initial pond volume" is the pond volume in cubic ft at the beginning of the runoff event. For a conservative design viewpoint, "initial pond volume" is assumed to be a volume up to the outlet weir elevation. This can be found from the depth-area-volume relationship of the pond. "Outflow" is the volumetric flow rate of water that is escaping from the pond through some outflow structure, such as, weir. The "initial outflow" refers to the outflow, if any, just prior to the runoff event entering the pond. It is assumed to be zero if the water level in the pond is below outflow weir level.
Click "Continue" to proceed.

Screen 13 – Metals Contamination Data

Check the appropriate box for calculation of Zn, Pb, Cu, or Cd effluent concentration. As each box is checked, a drop-down menu appears that lists default values for the pond influent concentration and particulate (TSS) partition coefficient. The partition coefficient is the ratio of particulate bound solid phase and liquid phase metal concentration. Please see the section 2.7.4, and 3.6.2 of the main report for details regarding metal partitioning. The default values of partition coefficient are based on "average" values from the Spokane and Vancouver storm event data base. Please see Table 14 and Figure 13 of the main report for the "average" values of the partition coefficients. It should be mentioned here that the default values are for initial approximation only and apply to similar conditions of Spokane and Vancouver storm events. ***Note: At least one box has to be checked for the model to operate properly.***

Screen 14 – Nutrient Concentration Requests

Check the appropriate box for calculations of total Kjeldahl nitrogen, ammonia, nitrate, total phosphorous, and orthophosphate removal. As each box is checked, a drop-down menu appears that lists the pond influent concentration and first order reaction rate constant. The model assumes a first order reaction for nutrient removal. The reaction can be written as:

$$\frac{dC}{dt} = -KC \tag{B.4}$$

Where, C is concentration of the nutrient, t is time, and K is the first order reaction rate constant. The default values of the rate constants are based on "average" values from the Spokane in-pond batch reactors. The user can refer to sections 2.7.5, 3.6.1, and figure 26-28 for the details about the nutrient degradation rate constants. ***Note: At least one nutrient has to be checked for the model to operate properly***.

Screen 15 – Data Requests

The values for initial nutrient concentration apply to values that exist in the pond *just prior to* the runoff event.

Click "continue" to proceed.

Screen 16 – Data Requests

The number of data sets in the depth area and particle size fraction is the number of x-y data pairs used to define pond depth verses pond surface area and the data pairs used in the particle size distribution (PSD) data. Note that the default number of data sets for the particle size data is 30. This is greater than what is normally used for a typical sieve analysis and results from the use of an automated particle size analyzer for sediment that passed the #200 U.S. standard sieve. Click "Continue" to proceed.

Screen 17 – Depth-Area Relationships

The depth-area relationship requires the input of pond volume, plan area, and wetted surface area as a function of pond water surface elevation. The wetted surface area refers to the area of the pond bottom in contact with the water and is used to determine water loss from infiltration. The wetted pond bottom area is less than 1 percent greater than the plan area for wide shallow ponds and therefore, the plan area data can be used in both columns if wetted pond volume data is unavailable. A typical depth-area-volume relationship for Spokane wet pond is shown in Table 21. For an existing wet pond a survey is required to establish a contour plot. The contour plot of Spokane pond is shown in Figure 2 of the main report. An example is provided here to calculate contour volume from contour plot.

At elevation (E_1 =100 ft), Area A_1 = 1000 ft2

At elevation (E_2 =101 ft), Area A_2 = 1100 ft2

Volume between Elevation E_1 and E_2, $\Delta V = \frac{A_1 + A_2}{2} \cdot (E_2 - E_1) = 1050$ ft3.

Total volume at a particular elevation is obtained by adding the volumes of successive contour volumes from the pond bottom.

The "review list" and "advance list" button allows user to enter and review each data pair. ***Note: Data must be entered from lower elevation to higher elevation.***

Click "Continue" to proceed.

Table 21. Depth-area-volume relationship for Spokane pond

Elevation (ft)	Volume (ft^3)	Plan area (ft^2)	Wetted surface area (ft^2)
1785	96.81	1175.4	1175.7
1785.5	1530.3	4572.9	4575.5
1786	4645.2	7875.7	7884.5
1786.5	9248	10399.4	10419.9
1787	14957.6	12377.9	12416.3
1787.5	21596.8	14174.8	14236.4
1788	29136.6	15968.4	16057.5
1788.5	37586.4	17896	18015.9
1789	47121.1	20235.1	20386.6
1789.5	57803.8	22531.8	22712.5
1790	69786.1	25623.2	25827.2

Screen 18 – Particle size fraction Data

The particle fraction data requires the input of particle size in micron and percent (by weight) passing that sieve size. Particle size distribution of TSS can be done by sieve analysis. However, if TSS contains a significant fraction of particles finer than #200 sieve, it is imperative to do delineate the finer size range. A typical sieve analysis result of Spokane pond dead zone sediment is shown in Table 22. The "review list" and "advance list" button in the screen allows user to enter and review each data pair. ***Note: Data must be entered from higher to lower sieve size and largest sieve size must have 100% passing.***

Table 22. Typical sieve analysis result

Particle size, micron	% finer
4760	100
2000	94.5
250	49.1
75	27.5
72.5	26.4

Particle size, micron	% finer
70	26.0
67.5	26.0
65	25.9
62.5	25.9
60	25.7
57.5	25.4
55	25.2
52.5	25.0
50	24.6
47.5	24.4
45	24.3
42.5	23.8
40	23.5
37.5	23.1
35	22.6
32.5	22.0
30	21.3
27.5	20.4
25	19.3
22.5	18.3
20	16.8
17.5	15.4
15	13.5
12.5	11.2
10	8.5
7.5	5.1
5	1.6
2.5	0.7

Screen 19 – User defined Inflow data

This screen is used to enter user specified flow to the wet pond if the user does not want to create a hydrograph. In that case, the user should have an understanding of average and/or peak discharge at the inlet of the pond. Note: At least three points are needed to enter a user defined inflow hydrograph. However, if the user wants a constant flow option, he should put the constant flow value in all the inflow ordinates (at least three). ***Note: the data of time coordinate of the hydrograph must be entered in ascending order, i.e., smaller to higher.***

Screen 20 – Output File

Enter the name of the file in which you would like to store the data calculated by the DSS. Give the filename extension ".txt", (e.g., "out.txt"). This file can be imported in

Excel and put in row-column format. Open Excel and click on "Open" in the File menu (or click on the open icon on the tool bar). In the Open window on the "Files of type" bar, select all files. In the "Look in:" bar select the location where the output file was saved and double click on the "txt" file. In the Text Import Wizard window, select "Delimited" and click "Next". Select "Tab" and "Comma" under "Delimiters" and click "Next" and then "Finish". The text file can now be saved as an Excel file for future access. However, some important on screen results will be shown by the model in the next two screens. Click "Continue" to proceed.

Screen 21: Results Summary 1

Sediment, flow, and metal removal summary information are presented in this screen. The first number represents the smallest particle size that will be removed completely by the wet pond under the specific conditions. Particles larger than that will also be completely removed but particles smaller than that will be partially removed. The output file in text format has the detailed removal results. The effluent concentrations of TSS and metals can be checked against surface water quality discharge criteria to establish whether the pond size is adequate. The user cannot go back to the previous screen once results are displayed in the screen. The user has to start over again to make changes in the design.

Screen 22: Results Summary 2

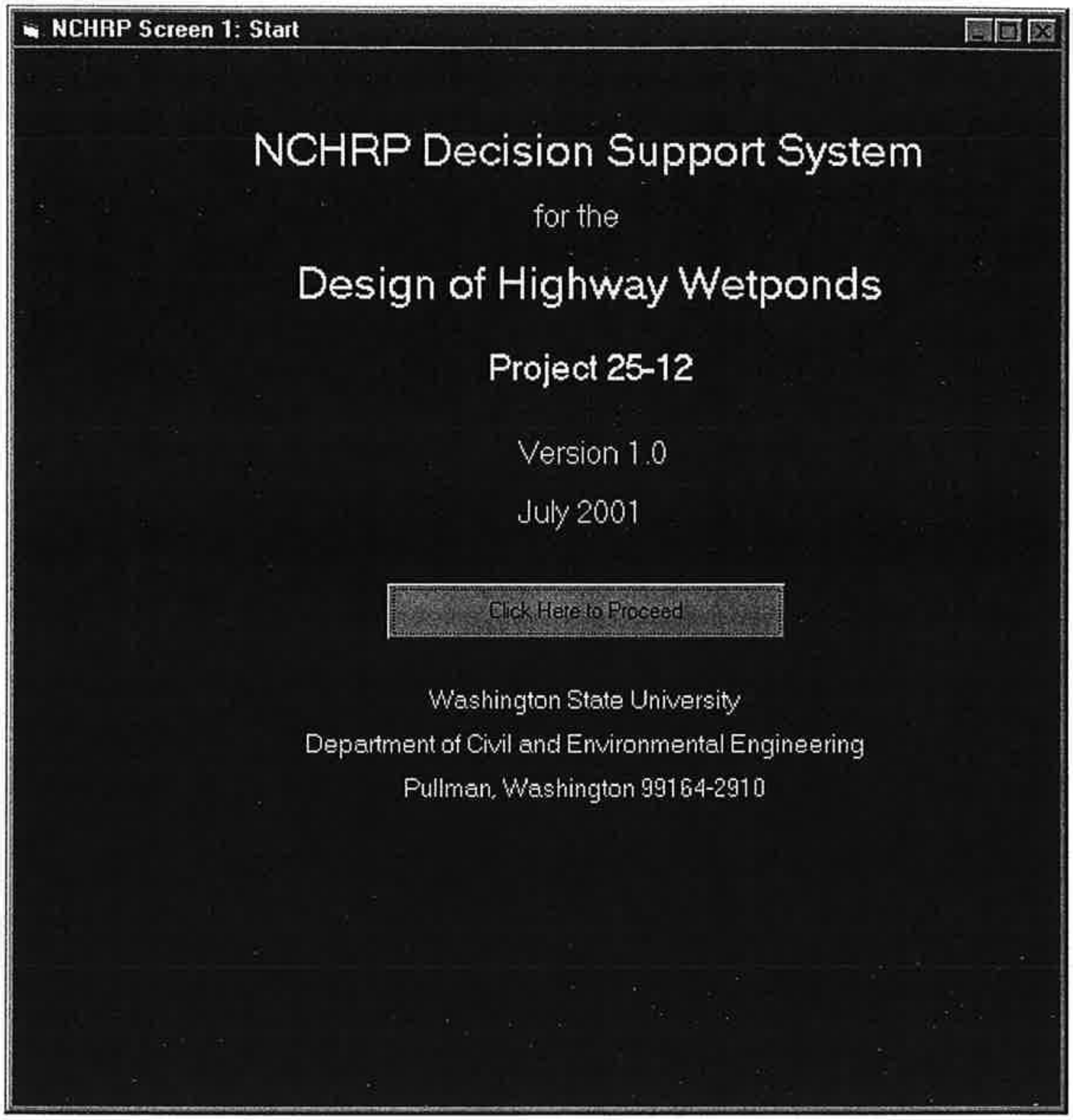
This screen gives the summary of maximum inlet and outlet concentration of nutrient that was checked in screen 14. The maximum effluent concentrations are checked with regulatory standards to satisfy the design objective. ***Note: The user cannot go back to the previous screen from this screen. The user has to start over again to see previous results, or to make changes in the design.***

Screen 23: Another Design

If the user selects "yes" the program will return Screen 3, "Determination of Storm Hydrograph", and input data can be changed as desired. If "no" is selected, the user exits from the program.

4 DESIGN EXAMPLE

A screen-by-screen example of the DSS operation is shown in next few pages. The user can run this example problem to become familiar with DSS.



NCHRP Screen 1: Start

NCHRP Decision Support System

for the

Design of Highway Wetponds

Project 25-12

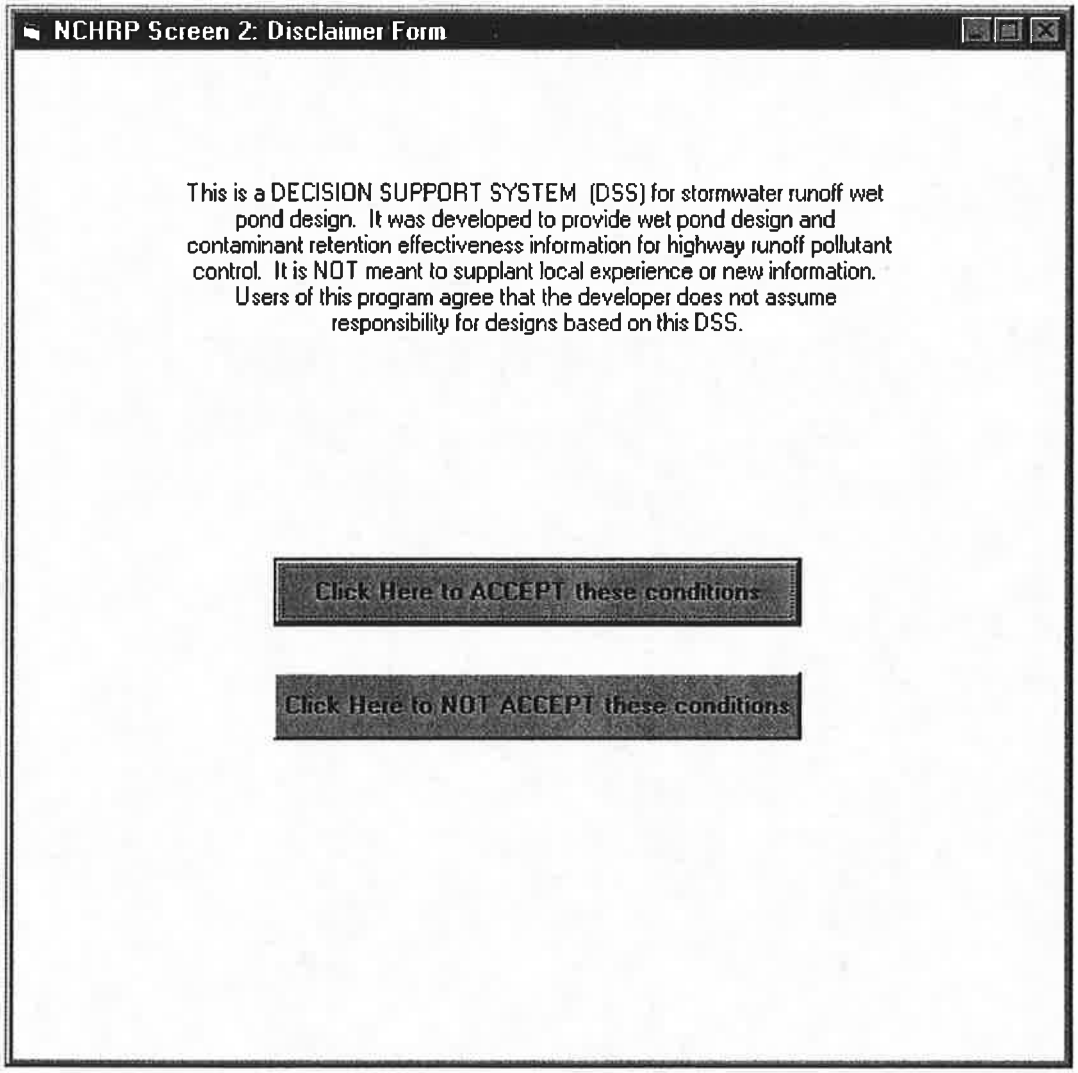
Version 1.0

July 2001

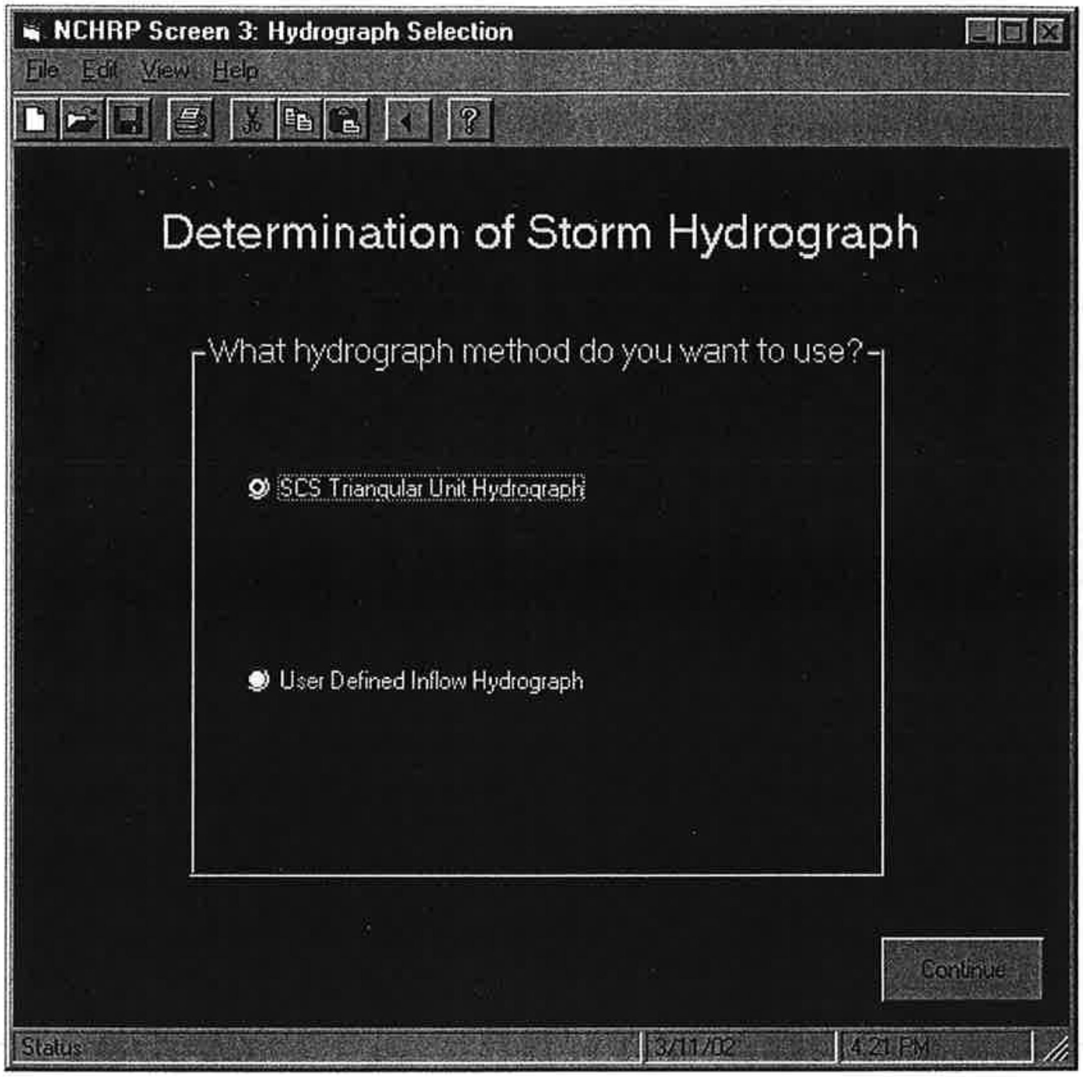
Washington State University

Department of Civil and Environmental Engineering

Pullman, Washington 99164-2910



This is a DECISION SUPPORT SYSTEM (DSS) for stormwater runoff wet pond design. It was developed to provide wet pond design and contaminant retention effectiveness information for highway runoff pollutant control. It is NOT meant to supplant local experience or new information. Users of this program agree that the developer does not assume responsibility for designs based on this DSS.

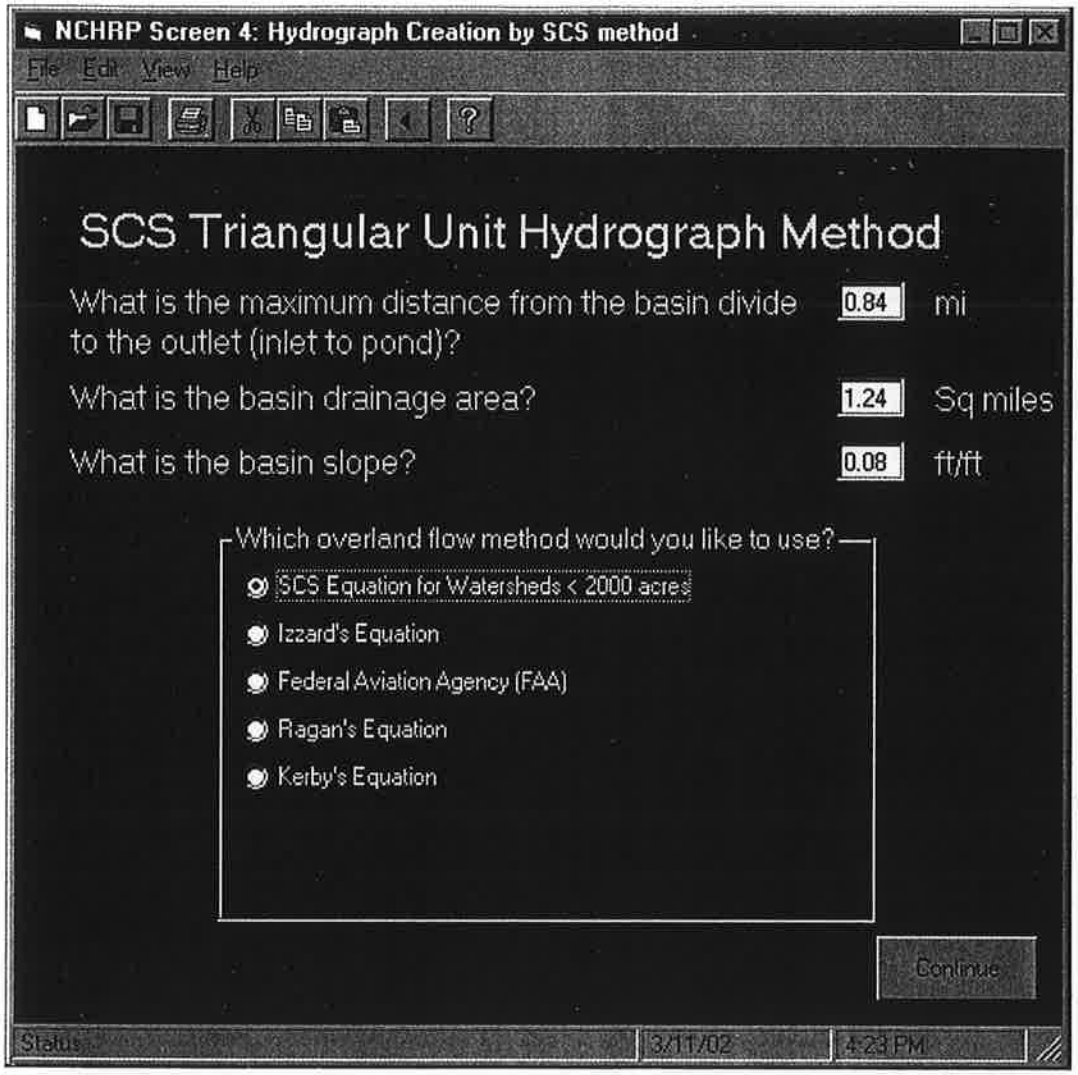


Determination of Storm Hydrograph

What hydrograph method do you want to use?

● SCS Triangular Unit Hydrograph

○ User Defined Inflow Hydrograph



SCS Triangular Unit Hydrograph Method

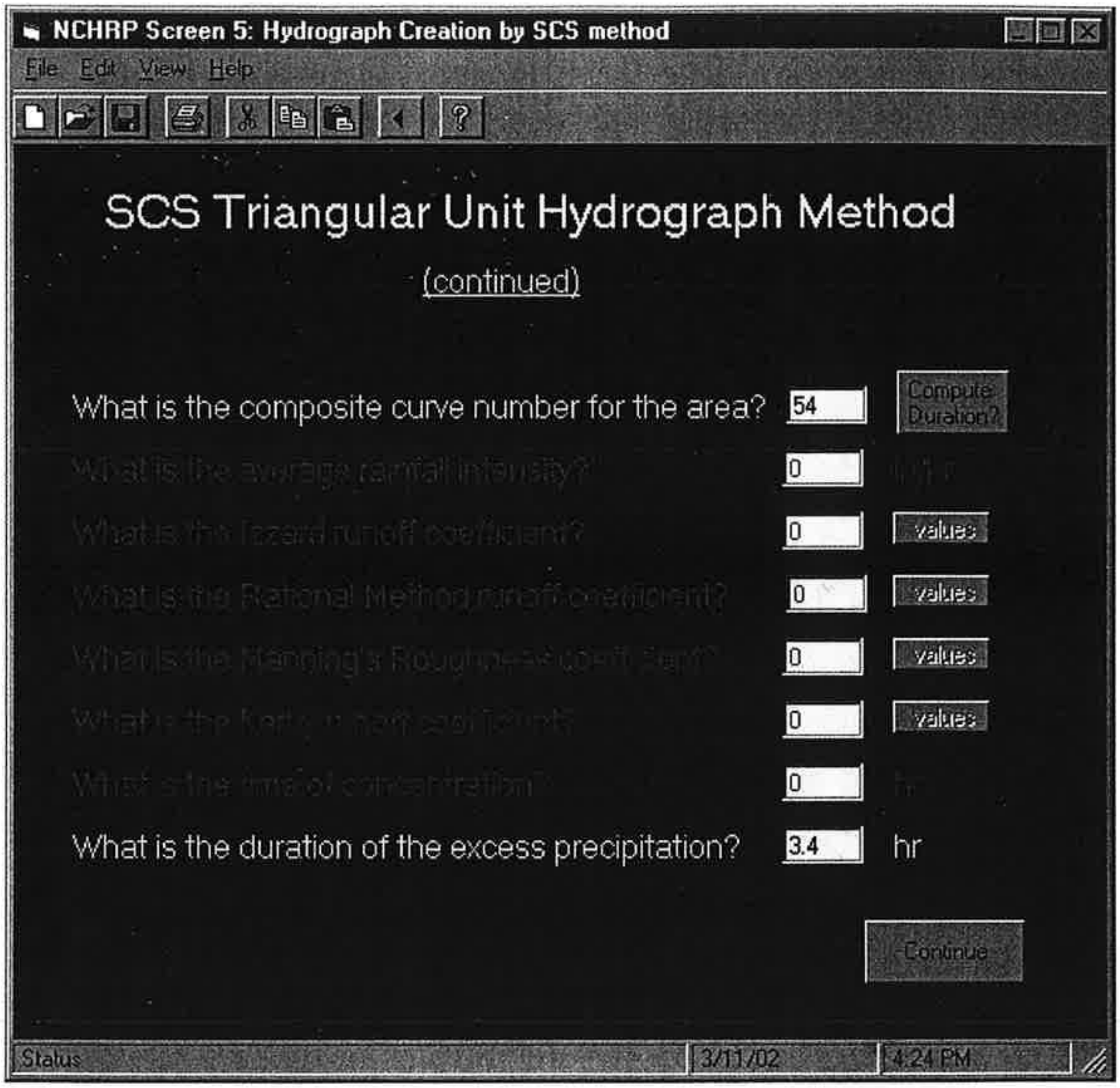
What is the maximum distance from the basin divide to the outlet (inlet to pond)? 0.84 mi

What is the basin drainage area? 1.24 Sq miles

What is the basin slope? 0.08 ft/ft

Which overland flow method would you like to use?

- ● SCS Equation for Watersheds < 2000 acres
- ○ Izzard's Equation
- ○ Federal Aviation Agency (FAA)
- ○ Ragan's Equation
- ○ Kerby's Equation



SCS Triangular Unit Hydrograph Method

(continued)

What is the composite curve number for the area? 54

What is the average rainfall intensity? 0 in/hr

What is the Izzard runoff coefficient? 0

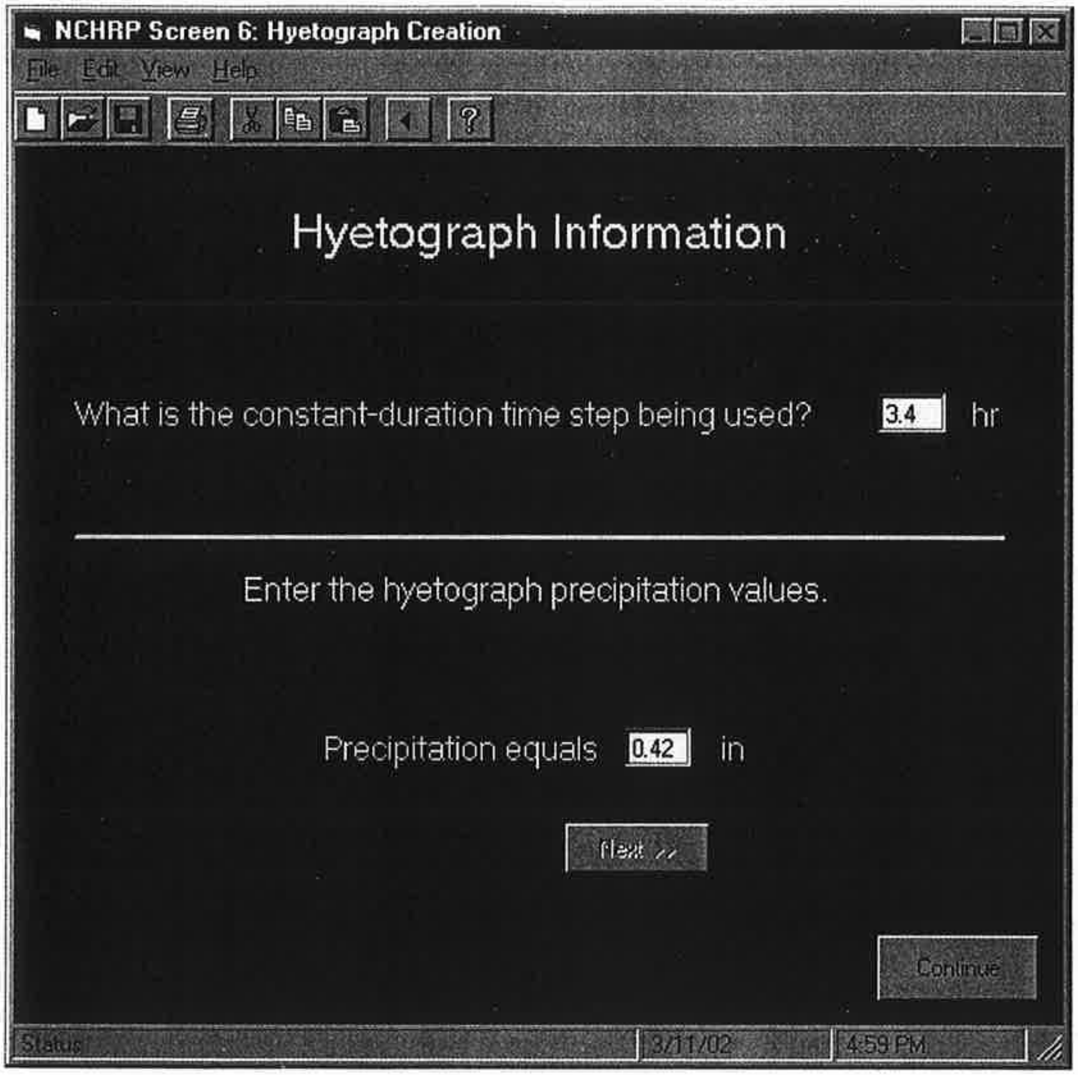
What is the Rational Method runoff coefficient? 0

What is the Manning's Roughness coefficient? 0

What is the Kerby runoff coefficient? 0

What is the time of concentration? 0 hr

What is the duration of the excess precipitation? 3.4 hr

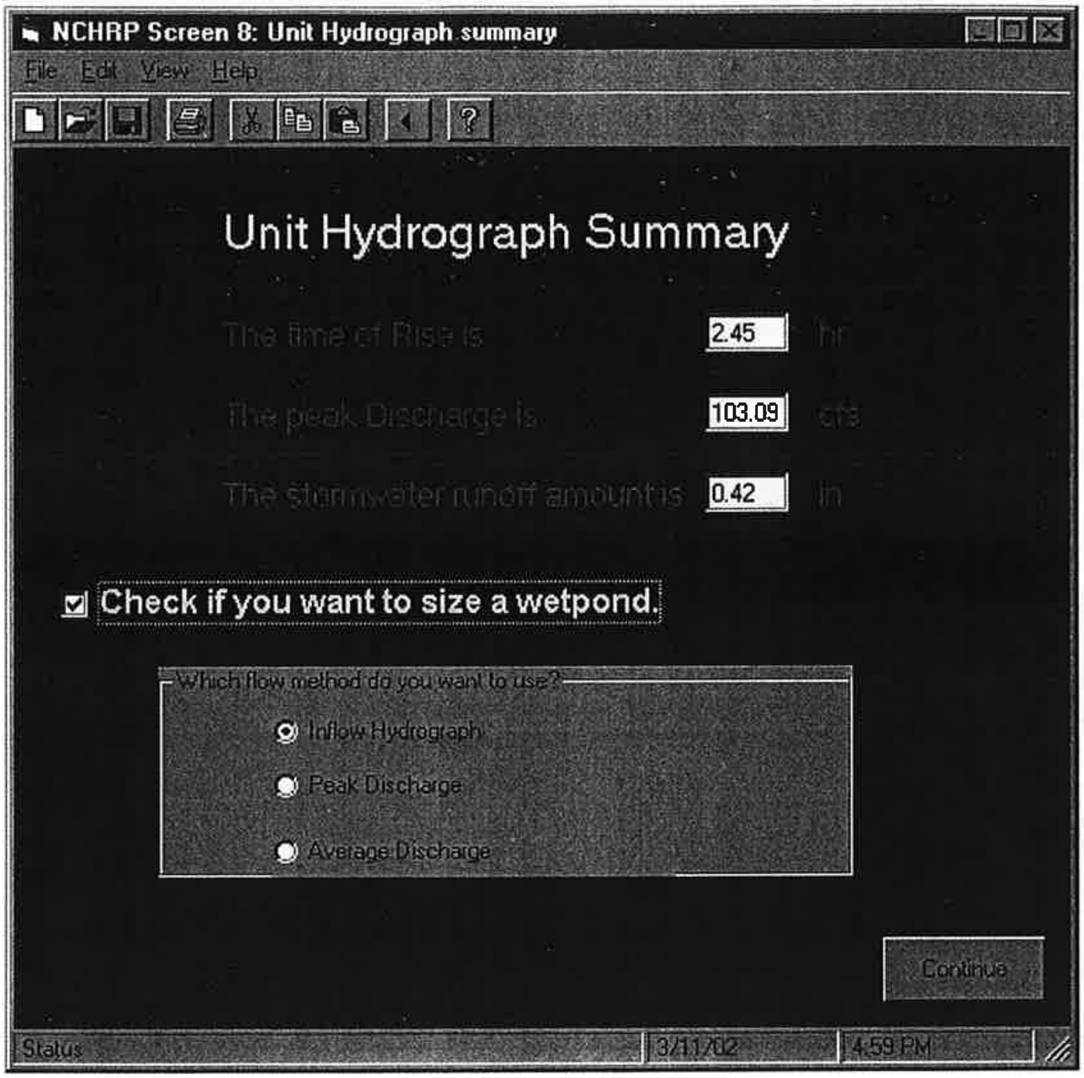


Hyetograph Information

What is the constant-duration time step being used? 3.4 hr

Enter the hyetograph precipitation values.

Precipitation equals 0.42 in



Unit Hydrograph Summary

The time of Rise is 2.45 hr

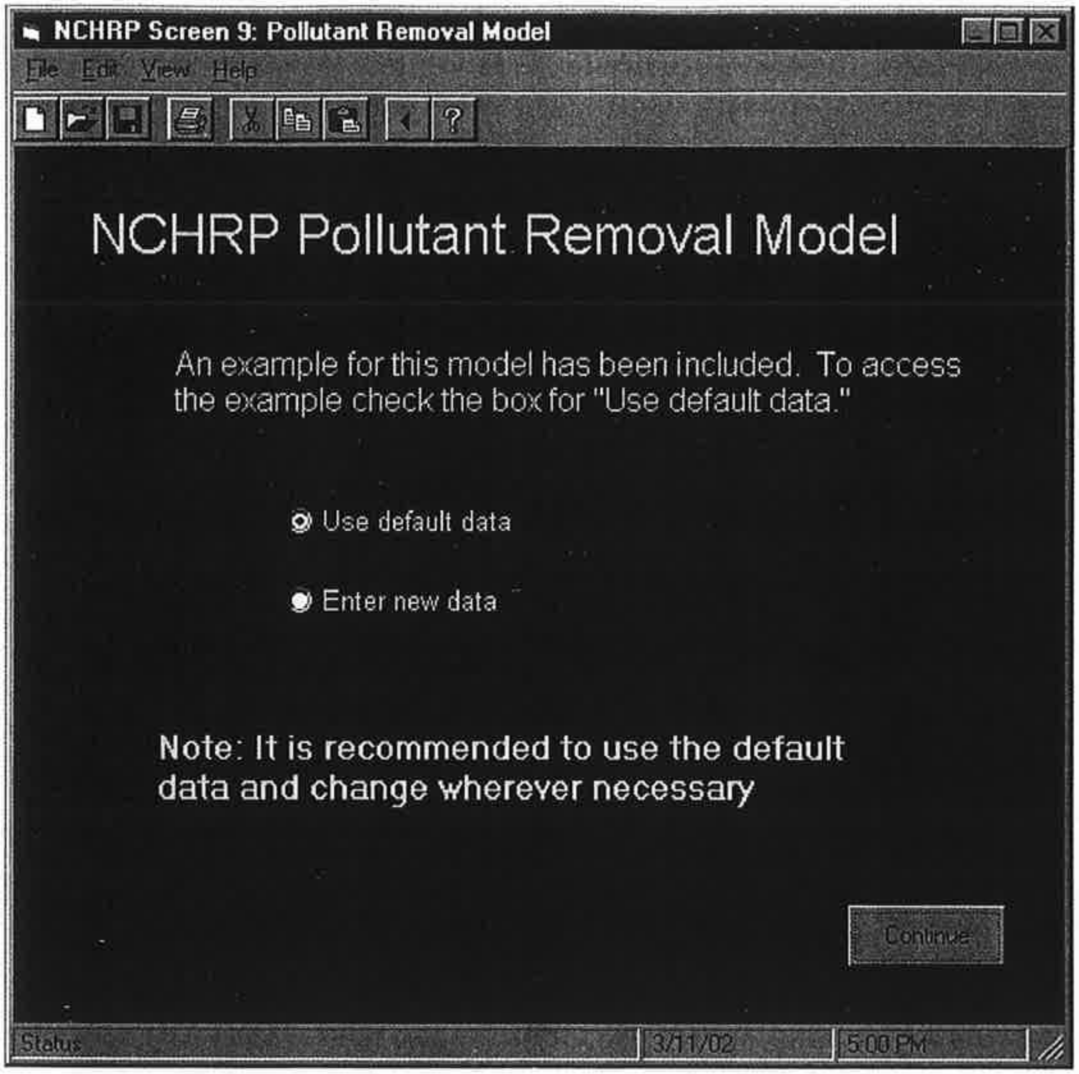
The peak Discharge is 103.09 cfs

The stormwater runoff amount is 0.42 in

☑ Check if you want to size a wetpond.

Which flow method do you want to use?

- ● Inflow Hydrograph
- ○ Peak Discharge
- ○ Average Discharge



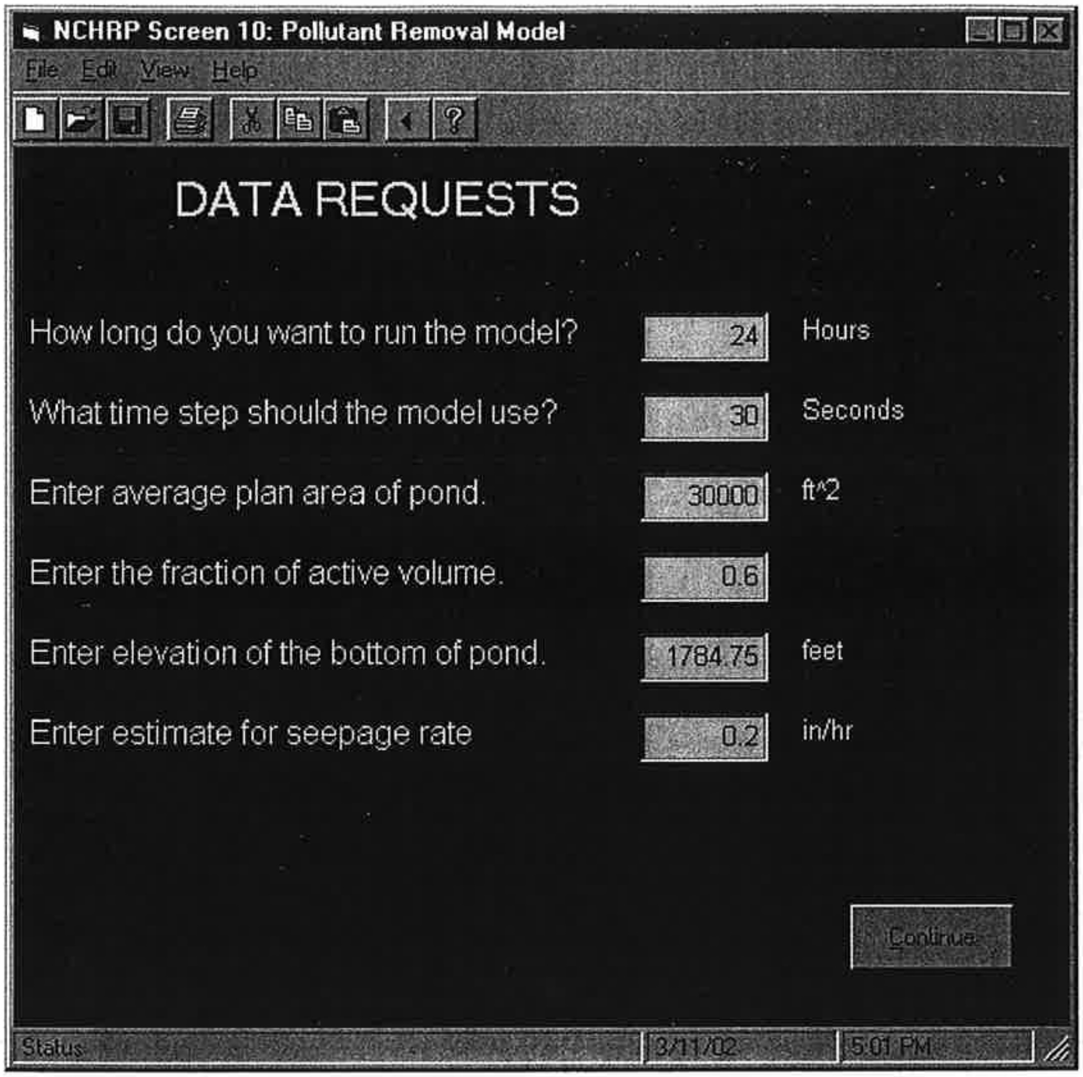
NCHRP Pollutant Removal Model

An example for this model has been included. To access the example check the box for "Use default data."

● Use default data

○ Enter new data

Note: It is recommended to use the default data and change wherever necessary



DATA REQUESTS

How long do you want to run the model? 24 Hours

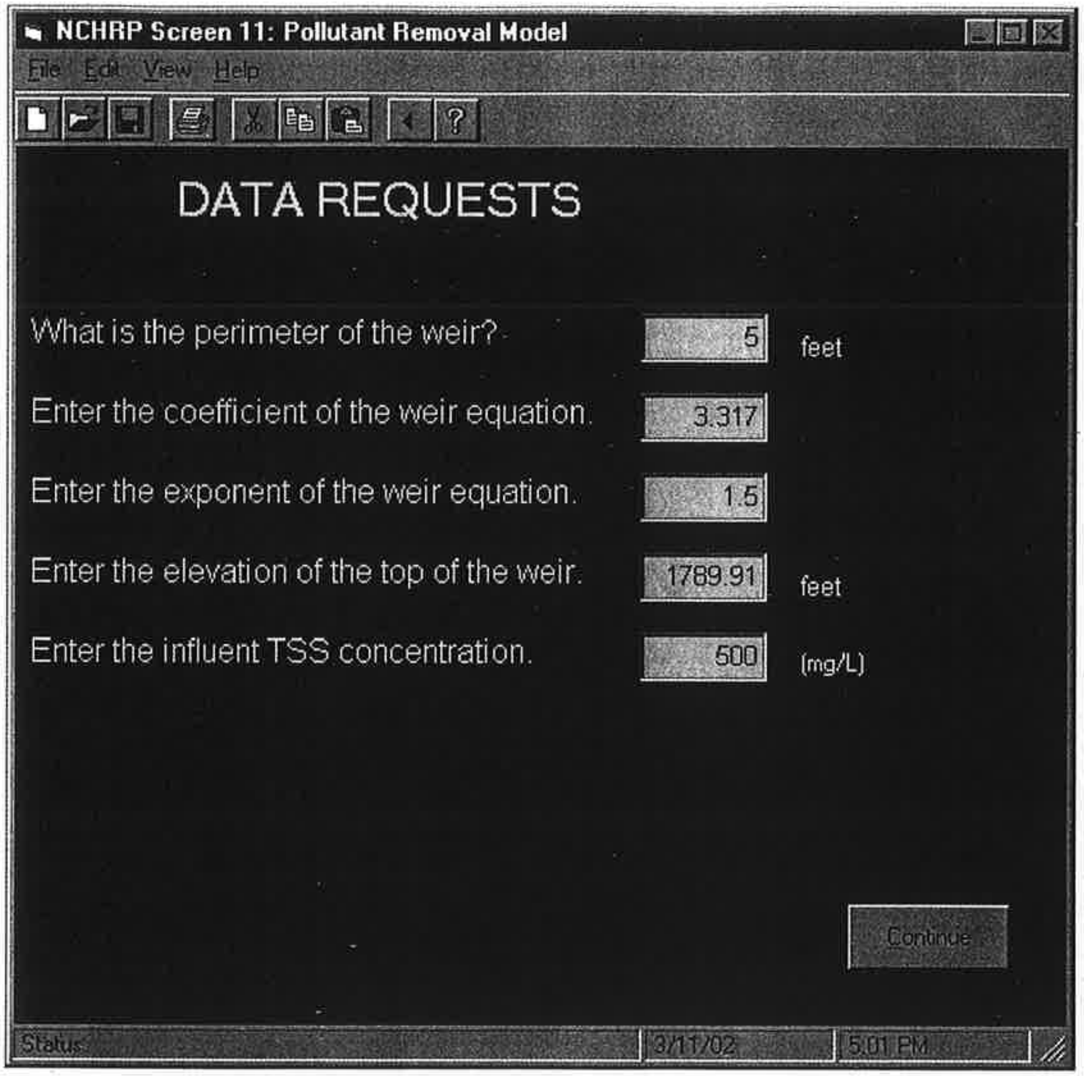
What time step should the model use? 30 Seconds

Enter average plan area of pond. 30000 ft^2

Enter the fraction of active volume. 0.6

Enter elevation of the bottom of pond. 1784.75 feet

Enter estimate for seepage rate 0.2 in/hr



DATA REQUESTS

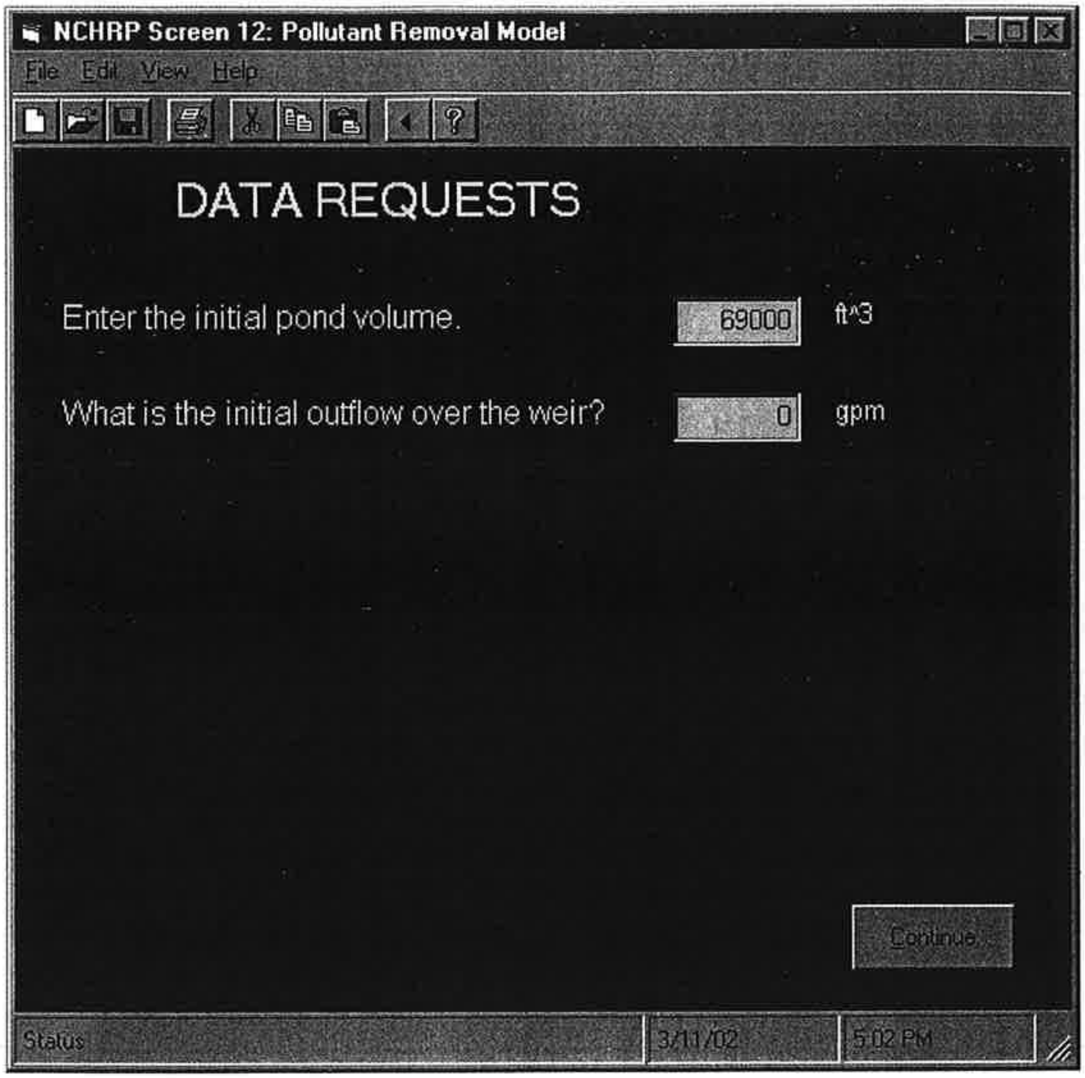
What is the perimeter of the weir? 5 feet

Enter the coefficient of the weir equation. 3.317

Enter the exponent of the weir equation. 1.5

Enter the elevation of the top of the weir. 1789.91 feet

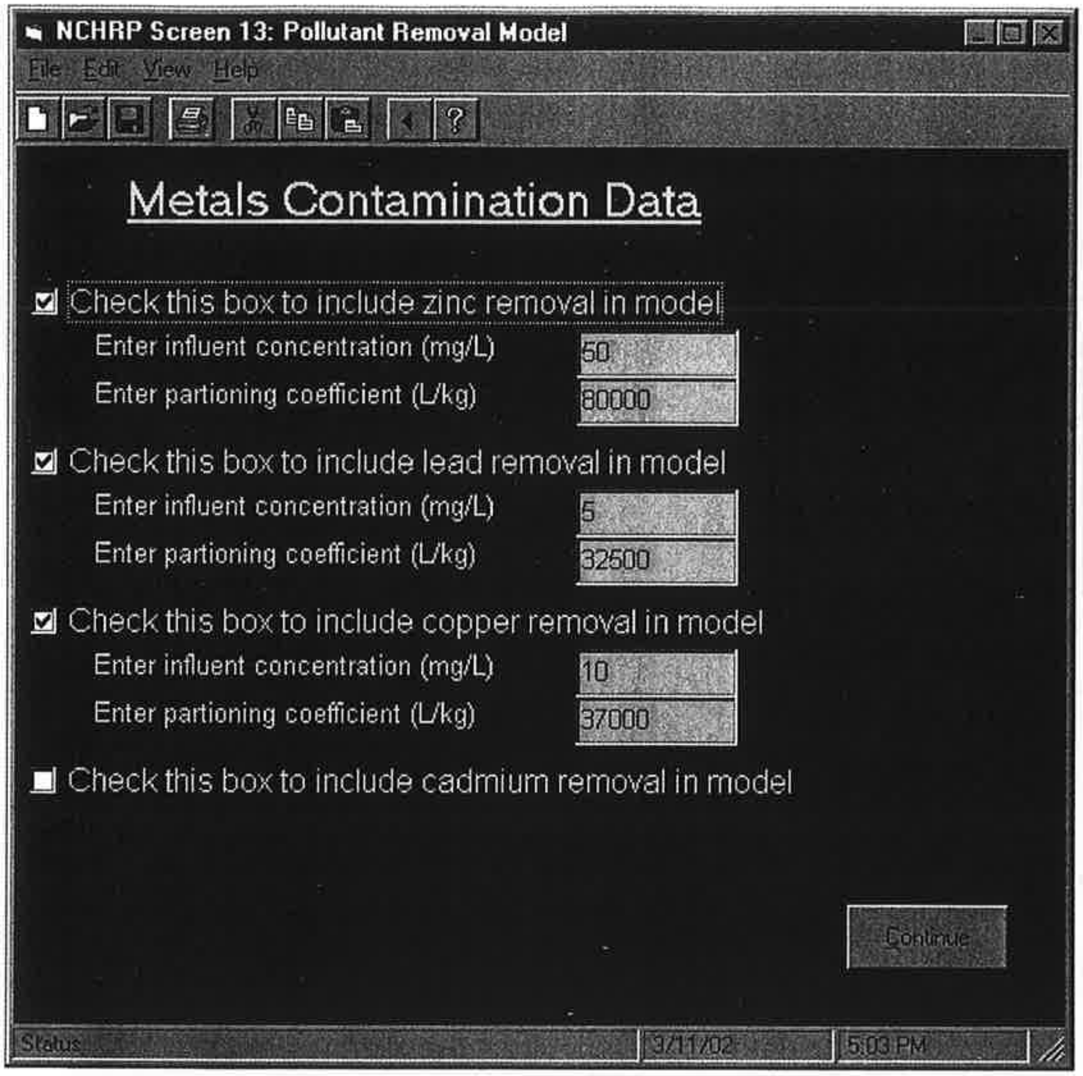
Enter the influent TSS concentration. 500 (mg/L)



DATA REQUESTS

Enter the initial pond volume. 69000 ft^3

What is the initial outflow over the weir? 0 gpm



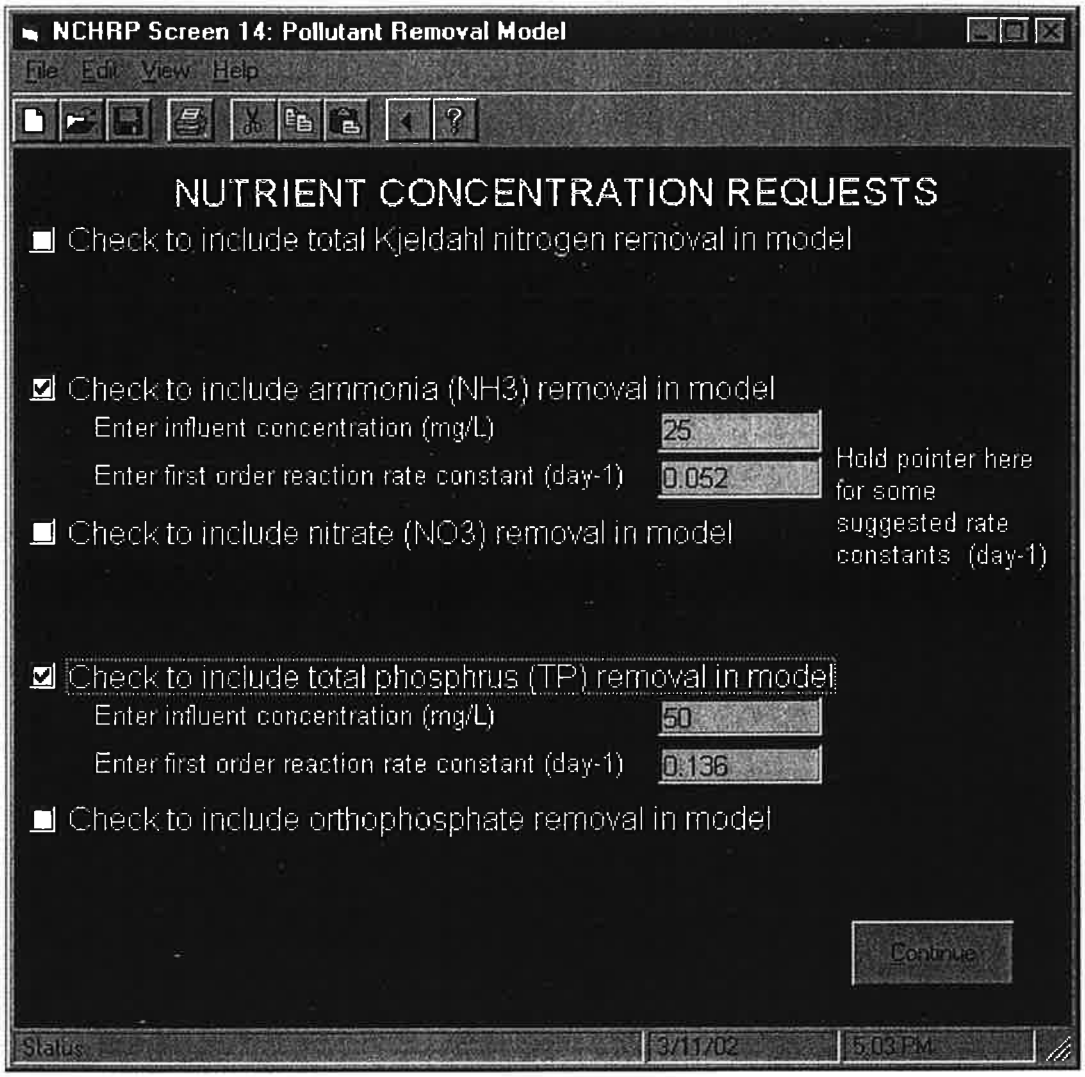
Metals Contamination Data

☑ Check this box to include zinc removal in model
Enter influent concentration (mg/L) 50
Enter partioning coefficient (L/kg) 80000

☑ Check this box to include lead removal in model
Enter influent concentration (mg/L) 5
Enter partioning coefficient (L/kg) 32500

☑ Check this box to include copper removal in model
Enter influent concentration (mg/L) 10
Enter partioning coefficient (L/kg) 37000

☐ Check this box to include cadmium removal in model



NUTRIENT CONCENTRATION REQUESTS

☐ Check to include total Kjeldahl nitrogen removal in model

☑ Check to include ammonia (NH3) removal in model

Enter influent concentration (mg/L) 25

Enter first order reaction rate constant (day-1) 0.052

Hold pointer here for some suggested rate constants (day-1)

☐ Check to include nitrate (NO3) removal in model

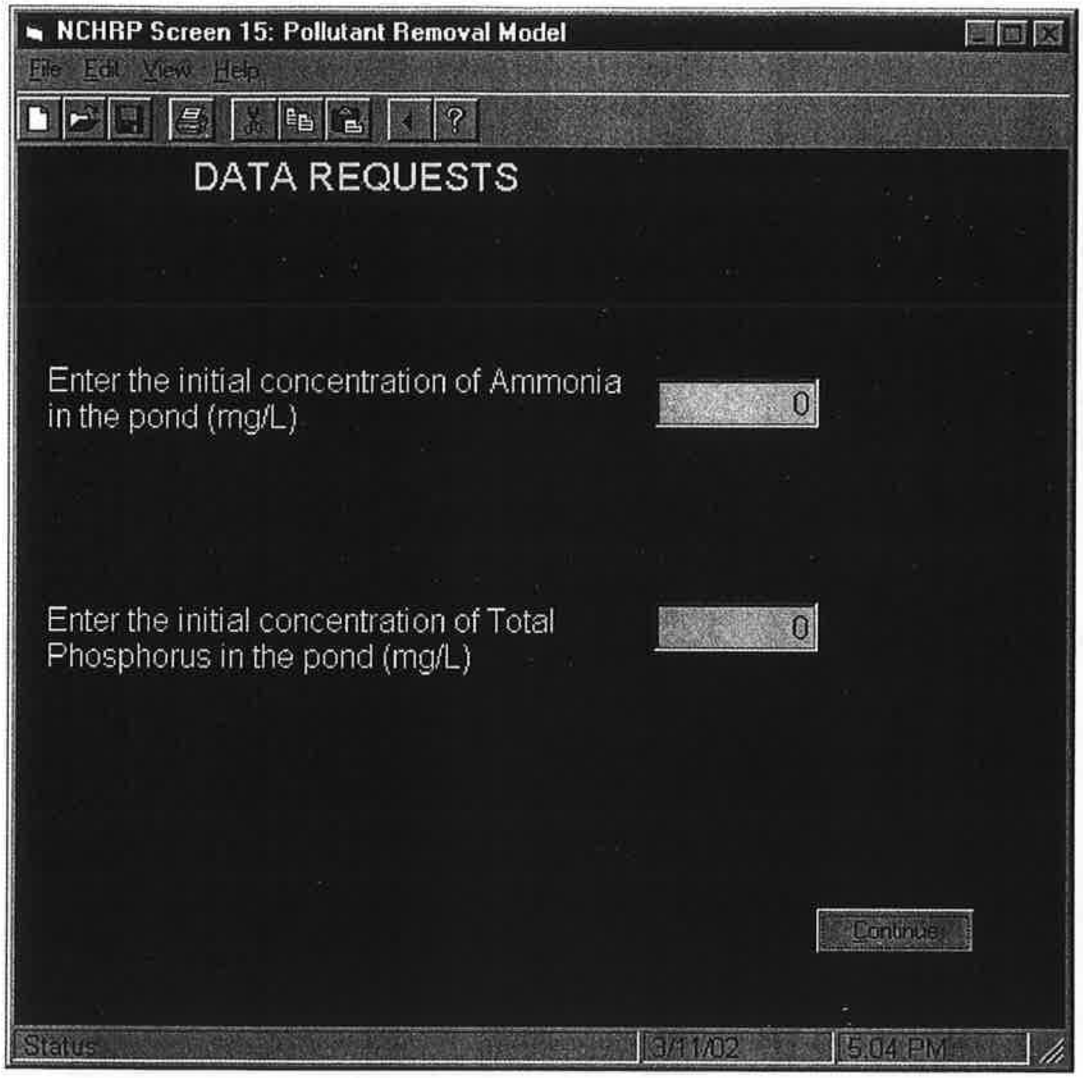
☑ Check to include total phosphrus (TP) removal in model

Enter influent concentration (mg/L) 50

Enter first order reaction rate constant (day-1) 0.136

☐ Check to include orthophosphate removal in model

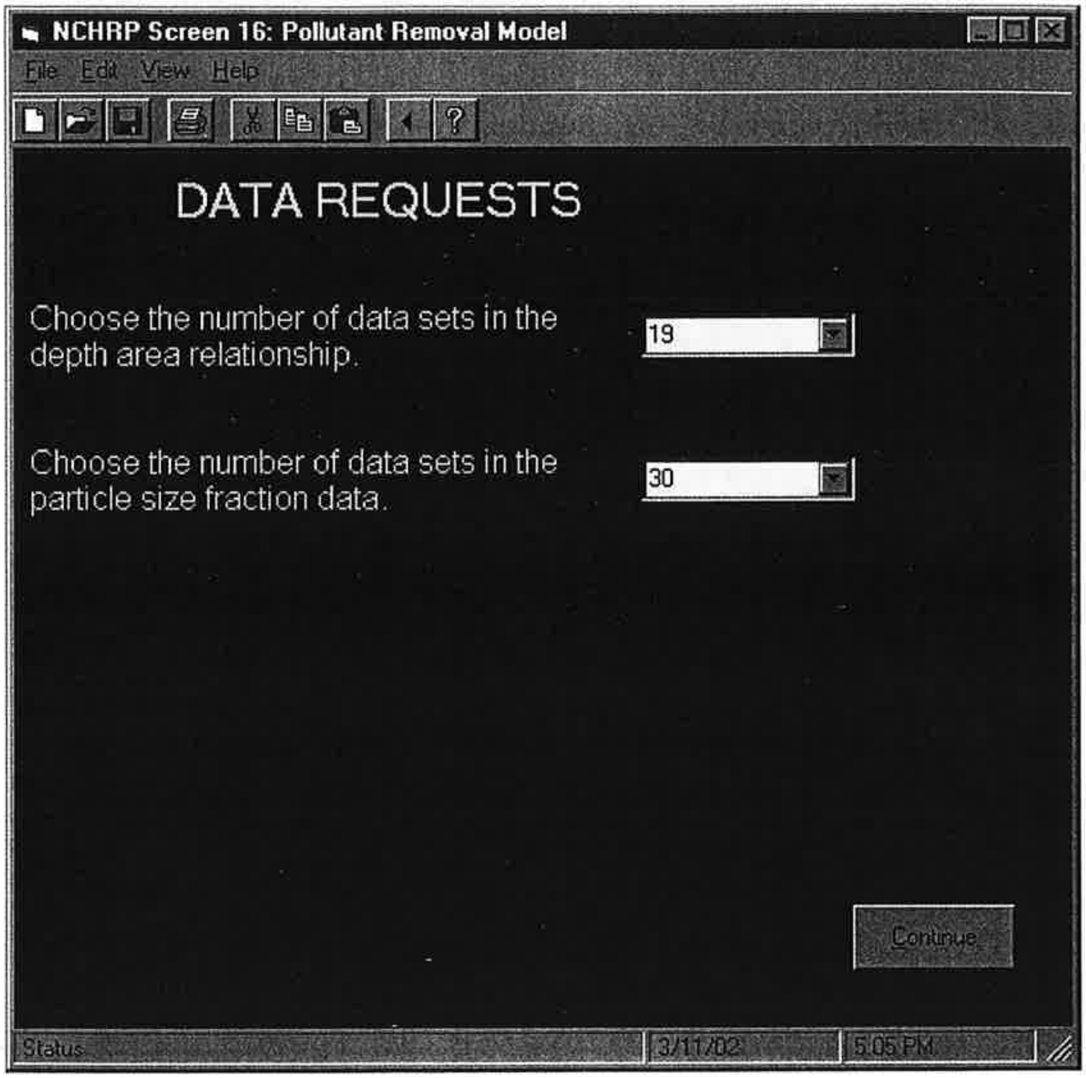
3/11/02 5:03 PM



DATA REQUESTS

Enter the initial concentration of Ammonia in the pond (mg/L) 0

Enter the initial concentration of Total Phosphorus in the pond (mg/L) 0

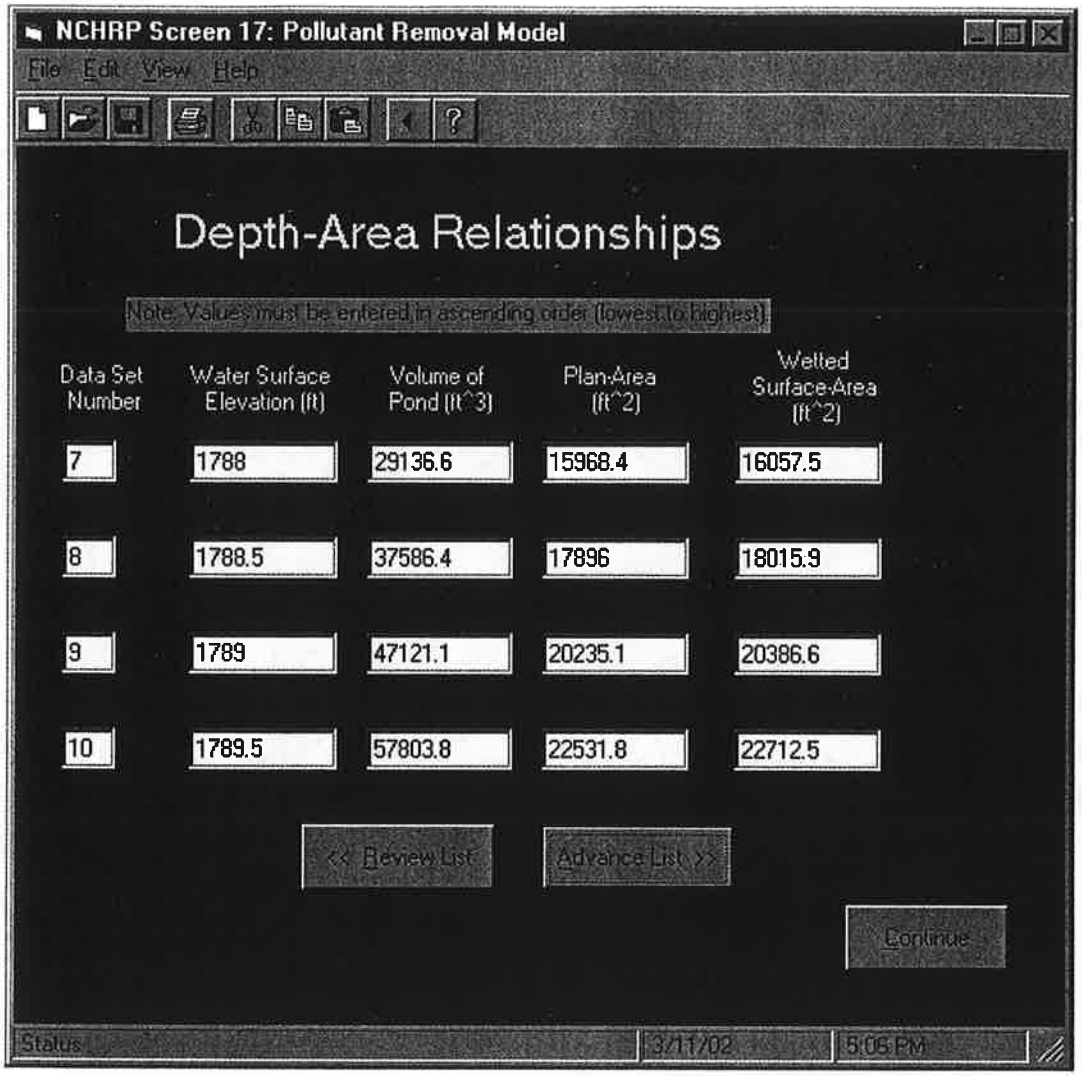


DATA REQUESTS

Choose the number of data sets in the depth area relationship. 19

Choose the number of data sets in the particle size fraction data. 30

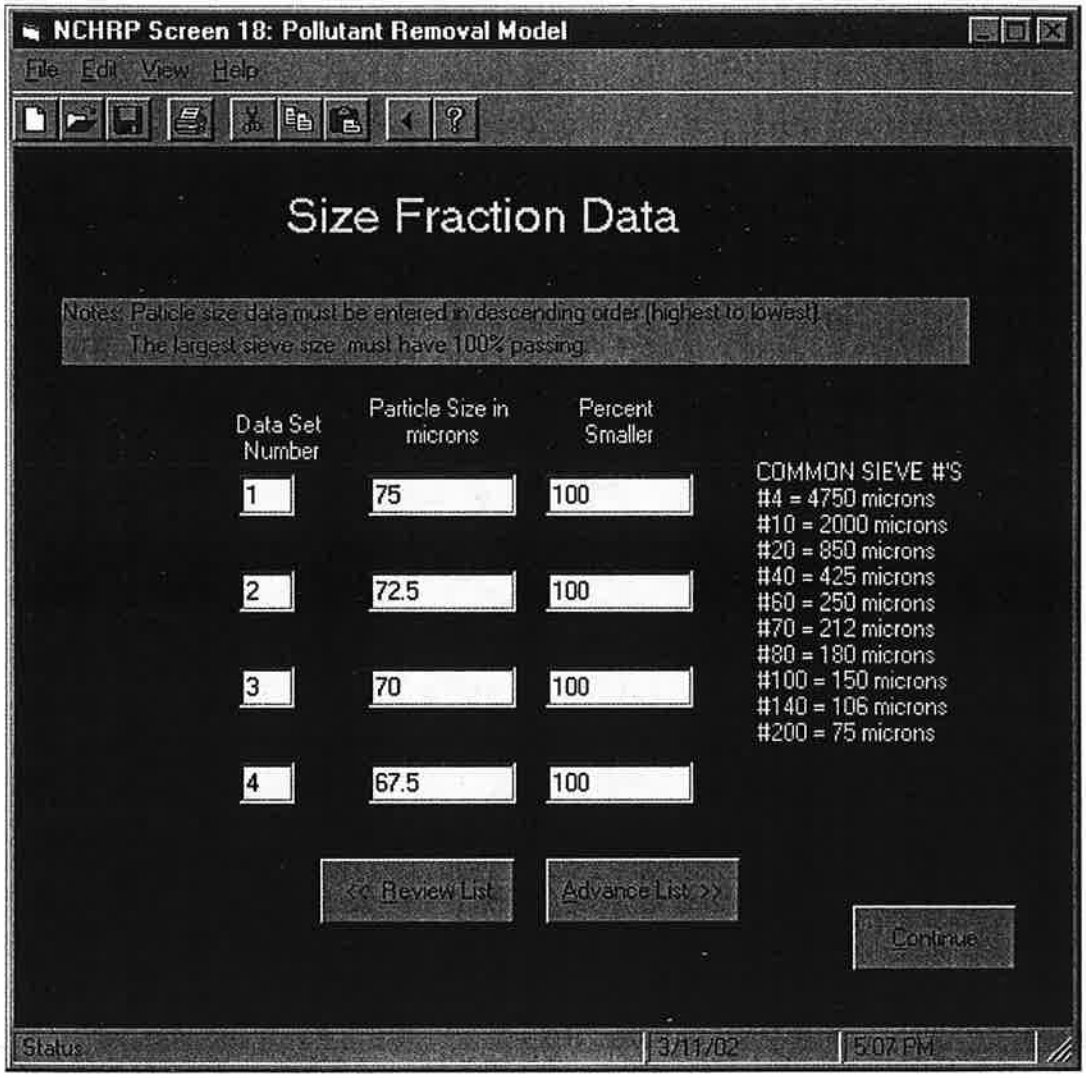
3/11/02 5:05 PM



Depth-Area Relationships

Note: Values must be entered in ascending order (lowest to highest).

Data Set Number	Water Surface Elevation (ft)	Volume of Pond (ft^3)	Plan-Area (ft^2)	Wetted Surface-Area (ft^2)
7	1788	29136.6	15968.4	16057.5
8	1788.5	37586.4	17896	18015.9
9	1789	47121.1	20235.1	20386.6
10	1789.5	57803.8	22531.8	22712.5

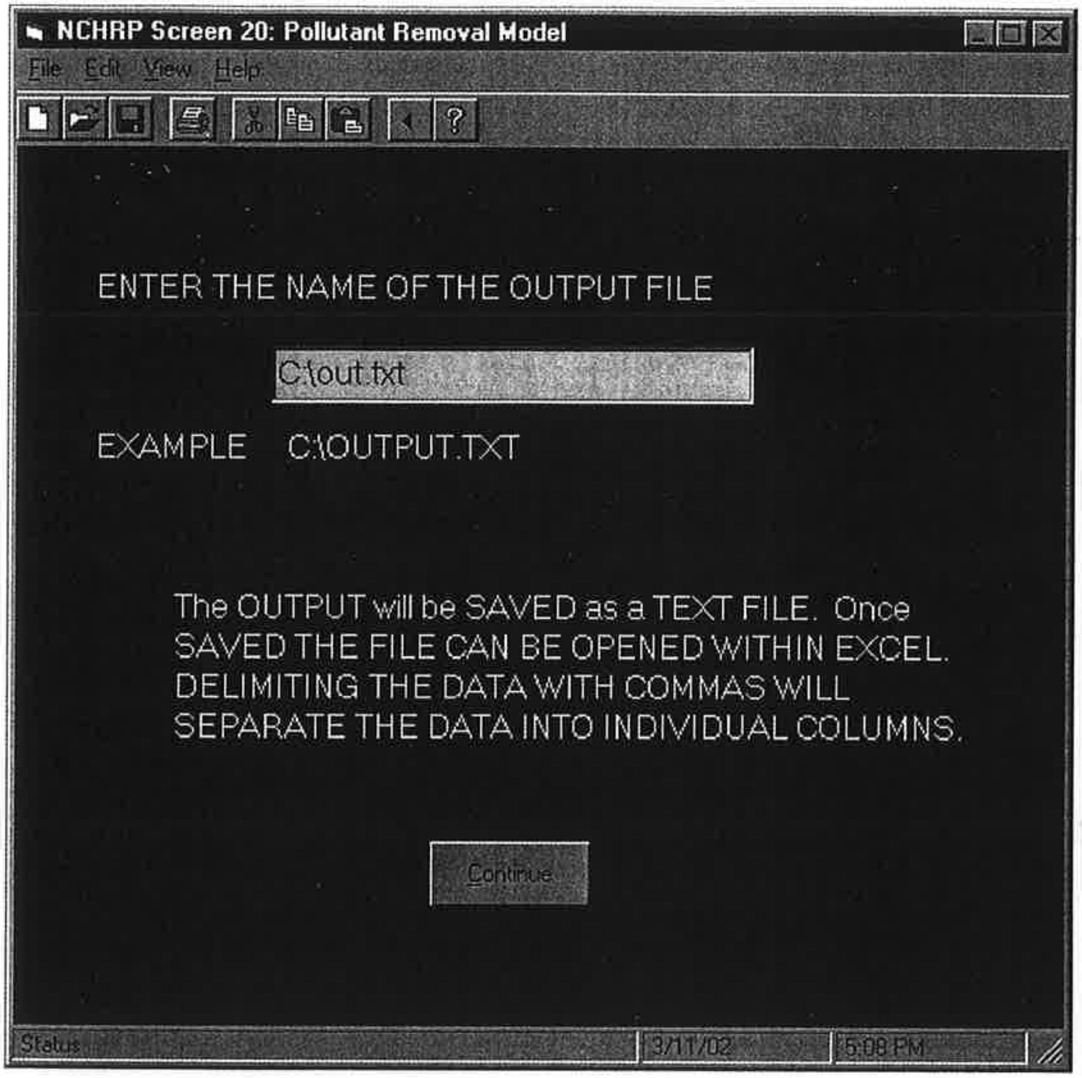


Size Fraction Data

Notes: Particle size data must be entered in descending order (highest to lowest).
The largest sieve size must have 100% passing.

Data Set Number	Particle Size in microns	Percent Smaller
1	75	100
2	72.5	100
3	70	100
4	67.5	100

COMMON SIEVE #'S
#4 = 4750 microns
#10 = 2000 microns
#20 = 850 microns
#40 = 425 microns
#60 = 250 microns
#70 = 212 microns
#80 = 180 microns
#100 = 150 microns
#140 = 106 microns
#200 = 75 microns

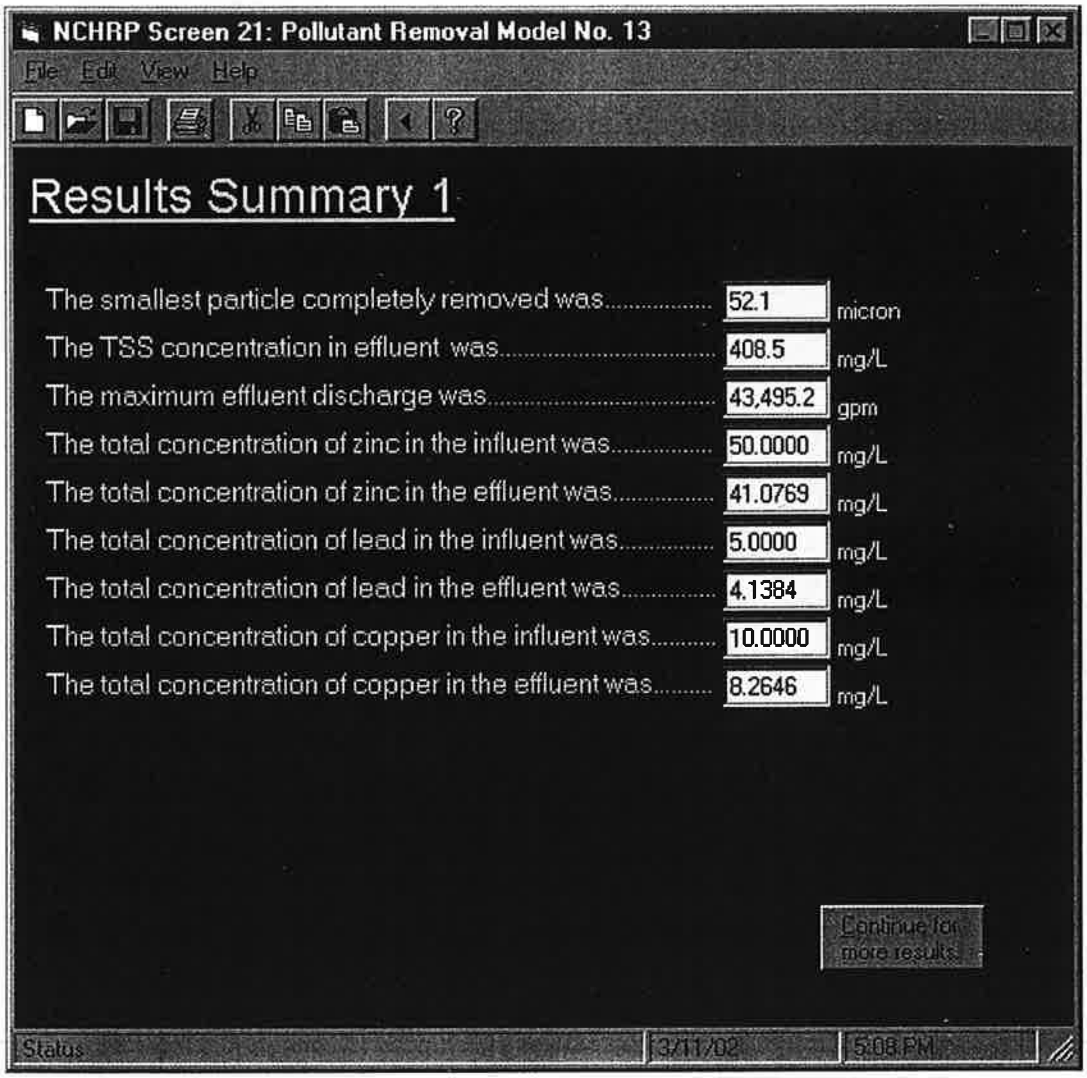


ENTER THE NAME OF THE OUTPUT FILE

C:\out.txt

EXAMPLE C:\OUTPUT.TXT

The OUTPUT will be SAVED as a TEXT FILE. Once SAVED THE FILE CAN BE OPENED WITHIN EXCEL. DELIMITING THE DATA WITH COMMAS WILL SEPARATE THE DATA INTO INDIVIDUAL COLUMNS.



Results Summary 1

The smallest particle completely removed was................. 52.1 micron

The TSS concentration in effluent was................................. 408.5 mg/L

The maximum effluent discharge was..................................... 43,495.2 gpm

The total concentration of zinc in the influent was................ 50.0000 mg/L

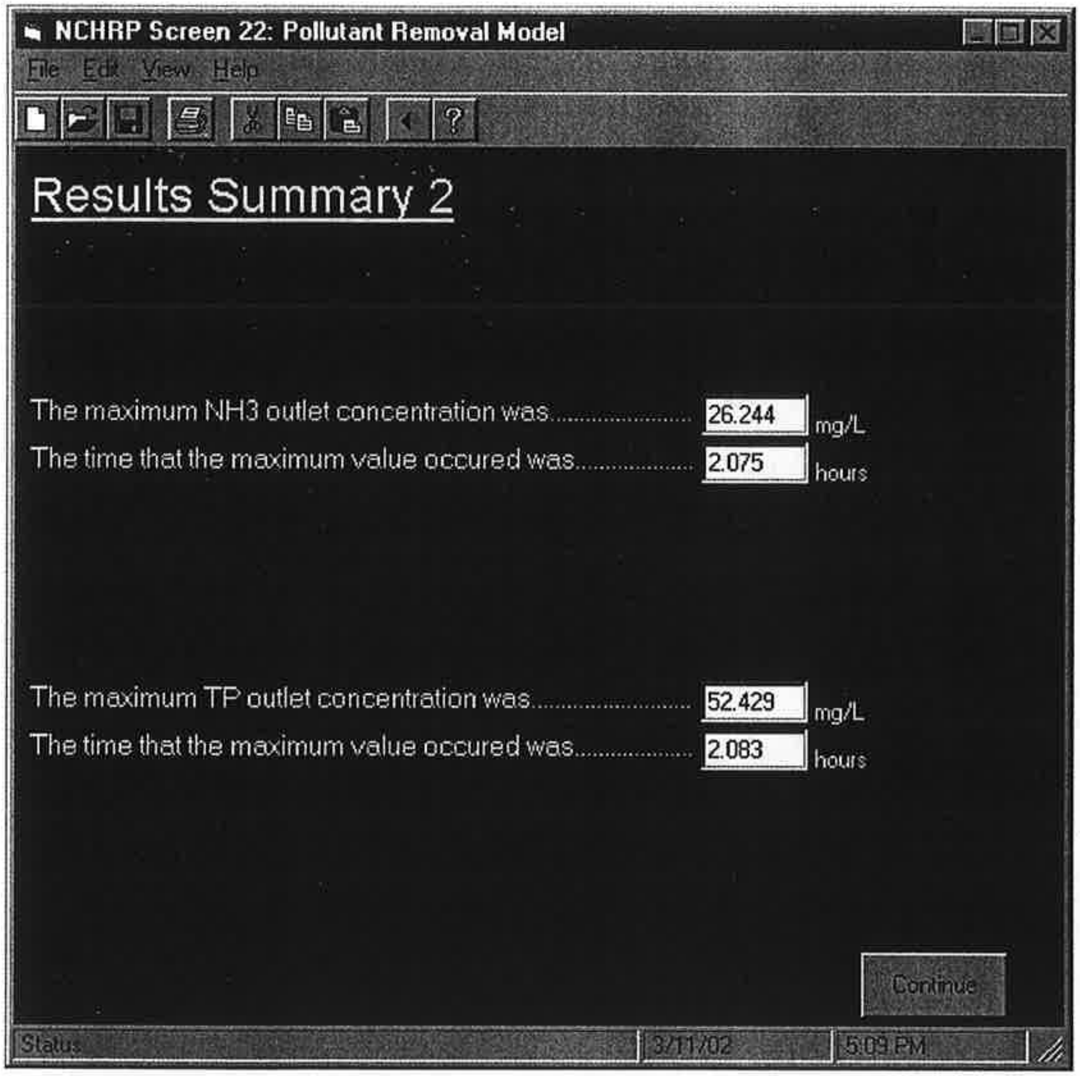
The total concentration of zinc in the effluent was................ 41.0769 mg/L

The total concentration of lead in the influent was............... 5.0000 mg/L

The total concentration of lead in the effluent was............... 4.1384 mg/L

The total concentration of copper in the influent was.......... 10.0000 mg/L

The total concentration of copper in the effluent was......... 8.2646 mg/L



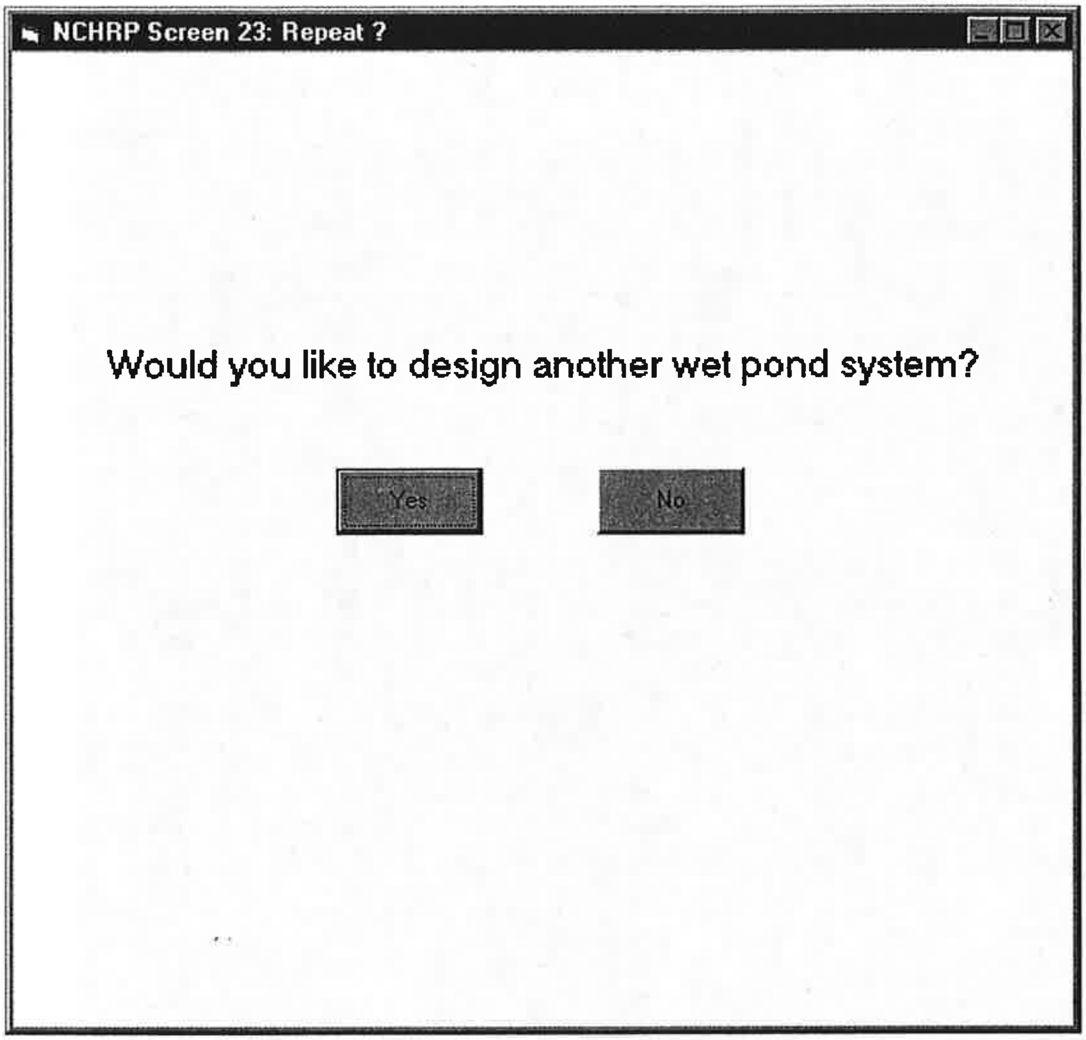
Results Summary 2

The maximum NH3 outlet concentration was........................ 26.244 mg/L

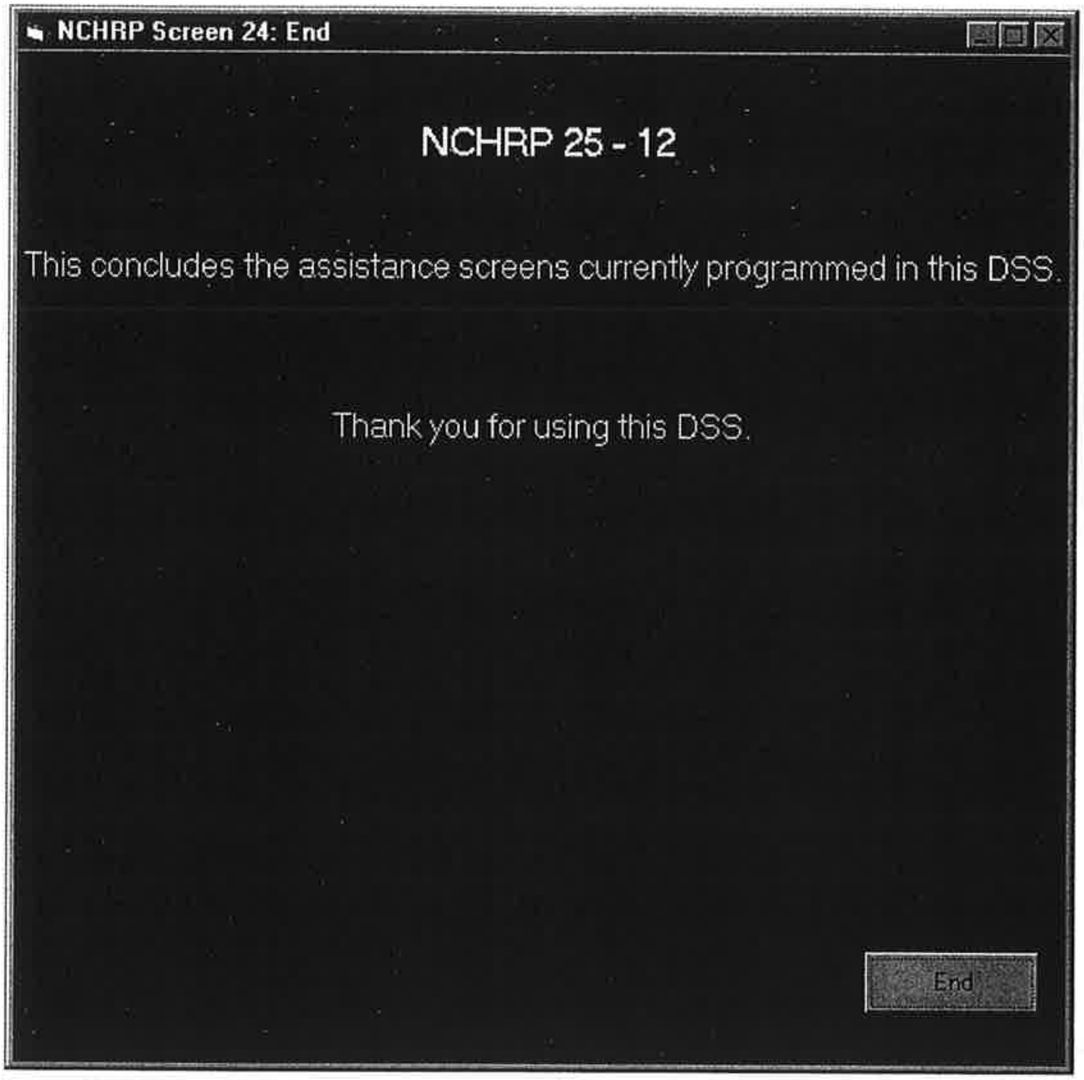
The time that the maximum value occured was.................... 2.075 hours

The maximum TP outlet concentration was........................... 52.429 mg/L

The time that the maximum value occured was.................... 2.083 hours



Would you like to design another wet pond system?



NCHRP 25 - 12

This concludes the assistance screens currently programmed in this DSS.

Thank you for using this DSS.

5 REFERENCES

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Chow, Ven Te. (1964). Ed., Handbook of applied Hydrology, 2nd Ed., McGraw-Hill Book Co, Toronto, Ontario.

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McCuen, R.H. (1998). Hydrologic Analysis and Design, 2nd Ed., Prentice Hall, Upper Saddle River, New Jersey.