Leytham

Pre-Filed Testimony of K.M. Leytham

Submitted on behalf of Appellant
Airport Communities Coalition

PCHB No. 01-160
ACC & CASE v. Dept. of Ecology & Port of Seattle

February 22, 2002

1. My name is Keith Malcolm Leytham. I am over the age of 18, am competent to testify, and have personal knowledge of the facts stated herein.

2. My curriculum vitae is attached as **Exhibit A**. I am a Professional Civil Engineer licensed in the State of Washington and a Professional Hydrologist registered with the American Institute of Hydrology. I am a principal of Northwest Hydraulic Consultants (**nhc**), located at Suite 350, 16300 Christensen Road, Seattle, Washington, 98188. I have over 20 years of specialized experience in surface water hydrology, including substantive experience with the surface water hydrologic modeling tools and analysis techniques being used by the Port of Seattle's consultants in their analyses and design of the Port's Master Plan Update Improvements for Seattle-Tacoma International Airport.

3. Northwest Hydraulic Consultants has been retained since October 1999 on behalf of the Airport Communities Coalition (ACC) to provide technical reviews of stormwater facilities and related streamflow impacts from the proposed 3rd runway and other development at SeaTac airport. I have been the principal responsible for Northwest Hydraulic Consultant's role in this review work. I have participated in review in several ways: in quality assurance and quality control of reviews conducted by my colleague Bill Rozeboom at **nhc**, and providing additional review in certain key technical areas including development and calibration of hydrologic models and characterization of the surface water hydrologic response of the proposed fill embankment for the 3rd runway.

HSPF Model Development

4. A calibrated hydrologic model which provides a reasonable representation of physical conditions in the study area is crucial to determining the likely impacts of proposed developments and for designing appropriate mitigation measures, whether they be for the control of peak flows or for the augmentation of low flows. For the bulk of its hydrologic modeling, the Port has used the EPA's HSPF continuous hydrologic simulation model. In my opinion, this is an appropriate choice of model, however the calibration of the model and the Port's characterization of hydrologic conditions in the project area are inadequate in several respects.

5. HSPF models have been developed and calibrated by the Port for Walker Creek, Miller Creek, and Des Moines Creek. Additionally, the Port has calibrated HSPF against observed runoff data from an area of embankment fill. The Port's most recent HSPF model calibration work is presented in the December 2000 Comprehensive Stormwater Management Plan (with updates through July 2001), hereinafter referred to as the SMP. Simulation results for low flow periods from the calibrated HSPF models are provided in more detail in the December 2001 Low Streamflow Analysis and Summer Low Flow Impact Offset Facility Proposal, hereinafter referred to as the Low Flow Plan.

6. The Port provides only limited documentation of its model calibration effort. The results presented are confined to plots of simulated against observed flows (in some instances at scales which are too small to allow detailed evaluation of model results) and summaries of annual volumes of simulated and observed runoff. Additional detail is provided for the Des

Moines Creek calibration in the form of flow duration curves and scatter plots. The Port presents no quantitative information on several key measures of calibration adequacy, including seasonal runoff volumes, runoff volumes in flood hydrographs, and peak flows. Furthermore, there is only scant information provided on interpretation of model calibration results, little in the way of explanation for apparent problems in model calibration, and no documented exploration of possible physical explanations for some of the major calibration problems. It is not clear from the information presented that the Port has attempted to use the model calibration work to fully understand the physical hydrology of the study area and the various runoff generation mechanisms which affect the flow regimes of the receiving waters. Finally, the Port presents no information on the implications of deficiencies in model calibration for analysis of project impacts and the design of mitigation measures. Given the significance of the proposed projects and the level of public interest, I would have expected to see more complete documentation of the modeling effort and findings.

Walker Creek HSPF Model Calibration

7. Calibration of the HSPF model to data from Walker Creek appears to have presented particular problems to the Port's consultants. Model calibration was conducted for water years 1993 through 1996 using data from two gage sites: Walker Creek at the Mouth (King County gage 42e) and Walker Creek at 171st Place (King County gage 42c) (a.k.a. Upper Gage and Walker Creek near Wetland). The Port presents in the SMP a summary of annual simulated and observed runoff amounts for the calibration period, plus information on periodic

field measurements of flows at the Upper Gage. Also presented are plots of simulated against observed flows for the two gage sites considered in calibration. No other quantitative information on Walker Creek model calibration results is provided in the SMP.

8. The final Walker Creek calibration in the SMP exhibits the following features:

- consistent under-simulation of peak flows at both gage sites;
- general over-simulation of winter and spring base flows at both gage sites;
- serious under-simulation of flood event runoff volumes at both gage sites, but particularly at the upper gage site, and,
- general under-simulation of base flows in the late summer and fall.

9. The Port appears to de-emphasize the problems in model calibration on Walker Creek by attributing differences between simulated and observed flows to gage malfunctions and errors in the observed data. However, no documentation, such as might be available from examination of stream gage rating records, is provided to support such claims. In fact, the data from the two gage sites appear to be quite consistent. The only obvious indication of gage error in the information presented is in the summer and the fall months of 1995 for Walker Creek at the Upper Gage where base flow amounts show unrealistic day to day variations and are much lower than one would expect.

10. A typical example of high flow simulation results for Walker Creek at the Upper Gage for November 1995 is shown in Figure B2-41 of the SMP, a copy of which is attached as **Exhibit B**. The plot shows severe under-simulation of peak flows and flood volumes. These

errors in peak flows and flood volumes are so large and so consistent throughout the calibration period that there appears to be a fundamental problem in the characterization of the hydrologic regime of upper Walker Creek.

11. The Port attempts to produce adequate simulations of stream base flows (low flows) on Walker Creek by assuming that 630 acres of land topographically within the Des Moines Creek basin provides groundwater contributions to Walker Creek. Delineation of the area identified as the "noncontiguous Walker Creek groundwater area", supported by groundwater mapping, is shown in the SMP model calibration report Figure B2-2, attached as **Exhibit C**. However, in the SMP, the Port has overlooked the fact that much of the area identified as providing groundwater contributions is in fact paved, with discharges from a substantial area being diverted to either the industrial waste water system (IWS) or the storm drainage system (SDS). After correction for these considerations, the actual pervious area capable of generating groundwater within the delineated Walker Creek noncontiguous groundwater area is probably on the order of 300 acres, as opposed to the 630 acres identified by the Port. Furthermore, as will be discussed later, some of the areas topographically in the Des Moines Creek basin which are assumed to provide groundwater to Walker Creek, also appear to be included in the Des Moines Creek HSPF model as providing groundwater to the headwaters of Des Moines Creek. Thus there seems to be a certain amount of double counting of groundwater contributions.

12. That the SMP's noncontiguous Walker Creek groundwater area may not provide 630 acres of pervious land appears to be recognized in a figure which appears for the first time in

the December 2001 Low Flow Plan, showing a northerly extension of the Walker Creek groundwater basin (**Exhibit D**). This northerly extension of the Walker Creek groundwater basin however seems to be a convenient renaming of the SMP's "noncontiguous Miller Creek groundwater area," depicted in **Exhibit C**. This "re-delineation" of the area contributing groundwater to Walker Creek is inconsistent with the groundwater mapping in **Exhibit C**.

13. The traditional approach to hydrologic model development involves calibration to a certain period of record (in this case water years 1993-1996), followed by model validation, that is, comparison of simulated against observed flows for a period of record that was not used in the model calibration. This has not been done formally for any of the gages used in model calibration, either in Walker, Miller or Des Moines Creek. However, the Port's Low Flow Plan does show a comparison of simulated against observed flows for the Walker Creek Upper Gage for water years 1991 and 1992 for the period June through November. These plots show that low flows are under-simulated by as much as 50% in that period (see Figures 3.5 and 3.6 of the Low Flow Plan, reproduced here as **Exhibit E**).

14. Finally, I note that there is a significant trend in the departure between simulated and observed flows over the course of the calibration period. In Table B2-9 of the SMP **(Exhibit F)** for Walker Creek at the Mouth, simulated runoff volumes for water year 1993 are 18% less than observed. This under-simulation is progressively reduced in subsequent years such that for water year 1996 the observed and simulated results agree almost precisely. No examination or comment on this trend has been provided. It is not clear whether this is simply a reflection of the

variability in model results or a result of changing physical conditions in the areas contributing runoff to Walker Creek during the calibration period.

15. In summary, with respect to Walker Creek:

i) The HSPF model results show substantial under-simulation of peak flows and flood volumes which suggests a fundamental problem in understanding either the sources of runoff or the runoff generation mechanisms within the upper Walker Creek basin. It is likely, in my opinion, that either the soils mapping for the basin is inaccurate or the permeable recessional outwash soils mapped in this basin are underlain at shallow depth by relatively impermeable material which results in greater runoff amounts.

ii) Modeling results show significant unexplained under-simulation of low flows for certain periods of record and,

iii) Assumptions with respect to the groundwater contributing area are inconsistent with actual conditions.

16. These problems are, in my opinion, significant deficiencies in the Walker Creek HSPF model which have not been addressed by the Port in either their assessment of existing hydrologic conditions or in their design of mitigation measures. The deficiencies demonstrate a continuing basic lack of understanding of the hydrologic regime of the Walker Creek basin. Without a better understanding of the hydrologic regime, it is not possible either to reliably identify and quantify project impacts or to design measures which can mitigate those project impacts with reasonable assurance.

Miller Creek HSPF Model Calibration

17. The Miller Creek HSPF model was calibrated to stream flow and rainfall data for water years 1993 through 1996 from two gage sites – Miller Creek at the Mouth (King County gage 42a) and Lake Reba Outflow (King County gage 42b) (a.k.a. Miller Creek at RDF). Modeling results are generally much better than those for Walker Creek, however concerns still remain related to both the adequacy of high flow simulations and characterization of the low flow regime.

18. Plots of simulated against observed flows for high flow events for Miller Creek at the Mouth show most simulated flood hydrographs peaking earlier than observed. The observed peak flows in the majority of large flood events are also under simulated. The Port claims that calibration problems are in part due to gage errors or gage malfunctions but, as in the case of the Walker Creek model calibration, fails to provide any documentation such as evidence of problems with stream gage ratings. The Port's documentation of apparent inconsistency in one event (January 1996, SMP Figure B2-22) is itself erroneous. The Port claims that observed flows at the upstream gage, Miller Creek at RDF, are reported as being higher than flows for Miller Creek at the Mouth, and illustrates the problem on Figure B2-22. In fact, it appears that the Port has simply mislabeled the figure (the legend is reversed). However, I agree that there still are inconsistencies in the observed data at the two gage site for this event.

19. At my deposition on 11 February 2002, I stated that, in my opinion, the low flow calibration for Miller Creek was inadequate since I believed that the HSPF representation of groundwater inputs to Miller Creek was inconsistent with more detailed groundwater modeling conducted with the Hydrus and Slice models. At that time, as stated at my deposition, I had not completed review of the most recent (December 2001) Low Flow Proposal. I have now completed that review and am satisfied that inconsistencies between HSPF and Hydrus/Slice modeling should **not** affect the HSPF low flow calibration. However, in the course of additional review I have determined that the Miller Creek HSPF model itself is in error because it fails to correctly incorporate groundwater inputs to Miller Creek from the "noncontiguous Miller Creek groundwater area" identified on SMP Figure B2-2 (**Exhibit C**). While the exact noncontiguous area will always be difficult to define, it is apparent from field observations and wetland mapping that there are significant groundwater inputs to the Miller Creek corridor upstream of SR-509 between South 168th Street and South 160th Street originating from outside the topographic boundaries of Miller Creek. Groundwater inputs in this general vicinity are consistent with the groundwater mapping presented in Figure B2-2 (**Exhibit C**). The Miller Creek HSPF calibration model, as presented in the SMP, appears to have omitted those inputs.

20. Inconsistencies remain in the manner in which the calibrated HSPF model and the Hydrus/Slice models are applied to evaluate the low flow impacts of proposed embankment construction. These issues are discussed by my colleague Bill Rozeboom in separate testimony in this case.

Des Moines Creek HSPF Model Calibration

21. The Des Moines Creek HSPF model appears to have been calibrated to streamflow and rainfall data for water years 1993 through 1996 from three gage sites – Des Moines Creek at the Mouth (King County gage 11d), Tyee Pond Inflow (King County gage 11c), and the Port's SDS3 gage. The period actually used for model calibration is not stated and model results are poorly documented; a complete assessment of modeling results is not possible with the information available. The model calibration appears to have emphasized matching simulated and observed flows for Des Moines Creek at the mouth and has de-emphasized the more relevant headwater gages at Tyee Pond (King County gage 11c) and SDS3. For reasons that are not known, no use seems to have been made in the calibration process of data from Des Moines Creek at Tyee Weir (King County gage 11f). This gage (which came into operation in 1995) is at a well-established weir control and provides high quality data.

22. Although the calibration report indicates good reproduction of overall observed runoff volumes for Des Moines Creek at the Mouth (Table B1-3), no comparable data on the adequacy of simulated volumes is provided for other gage sites. However, a comparison of simulated against observed flow durations presented for Tyee Pond inflow (King County gage 11c) shows consistent undersimulation of both high flows and base flows. Peak flows for large flow events are consistently undersimulated at this site.

23. Additional model results for low flow periods are provided in the Low Flow Plan. Results for Des Moines Creek at the Mouth are quite variable and as such are difficult to interpret. Low flows at Tyee Pond (King County gage 11c) are however consistently under-simulated. For example, simulated low flows in 1996 are only about one third of the observed flow (Low Flow Plan, Figure 4-11, shown in **Exhibit G**), suggesting a fundamental problem with the characterization of low flows. The deficiencies demonstrate a lack of understanding of the hydrologic regime of the upper Des Moines Creek basin. A better understanding of the hydrologic regime is again needed to reliably identify and quantify project impacts. Without a reliable quantification of project impacts based on a sound understanding of the hydrologic regime, it is not possible to design appropriate mitigation measures. It is also important to note that condition of Water Quality Certification I.1.e.i pertaining to monitoring requires an evaluation of post-project stream gage data against "*expected flow rates established by the model*", presumably to determine whether project impacts are being satisfactorily mitigated. This is clearly a meaningless condition in a situation such as this where the model's ability to simulate low flows is so poor.

24. The Low Flow Plan contains no information on the adequacy of low flow simulations at the Tyee Weir gage (King County gage 11f). This gage provides the most relevant high quality data representative of runoff from areas to be affected by proposed Port projects. Provision of low flow simulation results from this gage and discussion of the adequacy of such simulations was condition I.1.b.i of the August 2001 Water Quality Certification.

1998 Embankment HSPF Model Calibration

25. In order to characterize the hydrology of the proposed fill embankment, HPSF was calibrated against one month of observed runoff data (from February 1999) from a 19.4-acre area of the 1998 embankment site. The calibration results are presented in Appendix A of the SMP. The observed runoff from the embankment is flashy with high peaks and low base flow indicating low infiltration rates and significant amounts of surface runoff. The resultant HSPF model parameters show a hydrologic response similar to that of native till soils. Key HSPF model parameters for the embankment fill are summarized in Paragraph 28 below. Model simulation results, shown in **Exhibit H**, are adequate given the short period of observed data but tend to understate peak flows and overstate base flows. The period for which observed data are available was reasonably wet with total rainfall over the month of February 1999 of 6.95 inches and 1.04 in the wettest 24-hour period. By way of comparison the 2-year 24-hour rainfall for SeaTac Airport is approximately 2.0 inches. A longer period of observed runoff data from the embankment fill is needed to provide better confidence in model results.

Inconsistencies between Walker Creek, Miller Creek and Des Moines Creek HSPF Calibration.

26. There are a number of inconsistencies in the HSPF models resulting from the calibrations for Walker Creek, Miller Creek, and Des Moines Creek. These inconsistencies are primarily related to model parameter selection and treatment of groundwater.

27. Final calibrated values for key HSPF model parameters as extracted from the SMP are summarized below for till soils with a grass cover, for outwash soils with a grass cover, and for the 1998 embankment fill. This table shows a subset of the total parameter set, including the most important model parameters only.

Calibrated Values for Key HSPF Model Parameters

Model Parameter	LZSN (inches)	INFILT (in/hr)	AGWRC	DEEPFR	UZSN (inches)	INTFW	IRC
Till Grass							
Miller Creek	9	0.12	0.996	0.33	0.375	9.0	0.7
Walker Creek	4.5	0.03	0.996	0	0.25	2.0	0.15
Walker Creek groundwater area	4.5	0.12	0.999	0	0.25	3.0	0.5
Des Moines Creek	4.5	0.075	0.996	0.55	0.25	3.0	0.5
Outwash Grass							
Miller Creek	10.0	0.8	0.996	0.33	0.75	0	0.7
Walker Creek	5.0	0.8	0.996	0	0.5	0	0.5
Des Moines Creek	5.0	0.8	0.996	0.55	0.5	0	0.7
Embankment Fill							
1998 Embankment	7.5	0.02	0.90	0.10	0.28	6.0	0.15

Parameter definitions:

LZSN – lower-zone nominal storage – a measure of soil moisture storage potential.

INFILT – soil infiltration capacity

AGWRC – groundwater recession parameter – governs the rate at which groundwater discharge to the stream declines with time.

DEEPFR – fraction of groundwater which is lost to deep aquifers and which does not reappear in the stream system.

UZSN – upper-zone nominal moisture storage

INTFW – interflow index – governs the split between surface and shallow subsurface runoff.

IRC – interflow recession constant – governs the rate at which shallow subsurface flow rates decline with time.

These various model parameters govern the way in which an HSPF hydrologic model responds to rainfall inputs. For example, a reduction in the infiltration parameter INFILT will reduce the amount of rainfall which infiltrates to the groundwater system, with a corresponding increase in the amounts of faster responding surface and lateral subsurface runoff or interflow. Model parameters are typically selected through the calibration process to provide a reasonable match between simulated and observed flows within the bounds of a reasonable representation of the physical hydrologic system.

28. Till soil with a grass cover is the dominant soil/cover class (or PERLND in HSPF jargon) for pervious land under current conditions in the areas to be altered by proposed Port projects. It is also the PERLND assumed to generate groundwater in the Walker Creek

noncontiguous groundwater area. Note the wide range in parameter values for till/grass for the lower zone soil moisture storage parameter LZSN, the infiltration parameter INFILT, and the interflow parameters INTFW and IRC. The parameter set for till/grass for Miller Creek (high LZSN, moderate INFILT, high INTFW) reduces the amounts of surface runoff from till soils, and increases interflow and groundwater contributions, leading to runoff hydrographs with relatively low peaks and a relatively long time base. The parameter set for the same till/grass soil/cover class in the Walker Creek basin (moderate LZSN, low INFILT, and low INTFW) results in much larger amounts of surface runoff and corresponding reductions in interflow and groundwater, producing runoff hydrographs with a fast, flashy response and short time base. It is by no means clear why the same soils in two adjoining basins should be presumed to have such different hydrologic responses. A similar concern holds for the differences in parameter values between the Walker Creek basin and the immediately adjoining Walker Creek noncontiguous groundwater area.

29. Inconsistencies are also evident in the till/grass parameter sets for the Des Moines Creek and Walker Creek noncontiguous groundwater areas. As noted earlier, the Walker Creek noncontiguous groundwater area represents areas topographically within the Des Moines Creek basin which are assumed to provide groundwater contributions to Walker Creek. Surface runoff and interflow (i.e. shallow subsurface flow) generated from pervious surfaces in the Walker Creek noncontiguous groundwater area are assumed to contribute flow to Des Moines Creek and are included in the Des Moines Creek HSPF model. Note that the two parameter sets have different infiltration rates (INFILT of 0.12 inches/hr for the Walker Creek groundwater area and

0.075 inches/hr for Des Moines Creek) implying a different hydrologic response from physically identical areas in the two different models.

30. Finally I note that the Des Moines Creek HSPF calibration model presented in the SMP includes groundwater generated in some sub-basins which are also assumed to contribute groundwater to Walker Creek since they lie within the Walker Creek noncontiguous groundwater area. This double counting appears to occur for example for sub-basins SDS 5, 6, and 7.

31. Treatment of noncontiguous groundwater areas as in the Walker Creek and Miller Creek basins is a source of continuing uncertainty. A better understanding of low flow contributing areas and their hydrologic characteristics is needed to reliably quantify project impacts and design appropriate low flow mitigation measures.

Hydrologic Characterization of Fill Embankment

32. Of critical importance to the Port's assessment of the hydrologic impacts of embankment construction are the infiltration characteristics of the embankment fill. The Port has assumed that the embankment material is relatively permeable and that infiltrated water will be stored within the embankment to be released to streams and wetlands over an extended period of time. The storage of stormwater in the embankment and its subsequent release to down slope wetlands and streams is a key component of the Port's efforts to mitigate the low flow impacts of proposed master plan improvements.

33. The Port's current characterization of the hydrologic response of the fill embankment relies entirely on theoretical infiltration rates based on the grain size distribution or texture of fill material with little or no weight being given to the observed runoff data from the 1998 embankment fill which I discussed previously in Paragraph 26. Runoff data from the 1998 embankment fill showed a flashy response to rainfall with very low base flow amounts indicative of large amounts of surface or shallow subsurface runoff and little infiltration to sustain groundwater flows. As discussed in the following paragraphs, these observed data indicate that the Port's current analyses may overstate the ability of the embankment to mitigate for low flow impacts.

34. I, and other experts representing the ACC, had an opportunity to view a largely completed section of embankment during a site visit on the afternoon of January 28, 2002. Conditions during the visit were cold (temperatures probably in the mid-30s) and sunny with no rain. There were small amounts of snow on the ground in places (less than 0.5 inches) from snow over the previous 24 to 48 hours. Runoff from melting snow was flowing across the surface of the embankment and there were a large number of shallow puddles of standing water as shown in the photographs in **Exhibit I**. The surface runoff and standing water indicate low surface infiltration rates. These qualitative field observations are generally consistent with the observed runoff data from the 1998 embankment fill, which as noted earlier was apparently discounted by the Port. While the embankment appears to contain a relatively high percentage of coarse material, it is evident that there are sufficient fines to effectively seal the surface. Although I have not had the opportunity to view the embankment during rainy conditions, it is

evident from the surface runoff and standing water from melting snow that the embankment in its present state will produce large amounts of surface runoff during rainfall, with comparatively little infiltration. Completion of the embankment will presumably include some final grading, importation of topsoil, and seeding which will have some influence on its final hydrologic response. However, my qualitative field observations indicate that the completed embankment will likely produce much greater amounts of surface runoff and correspondingly less infiltration than has been assumed by the Port in its preparation of the December 2001 Low Flow Plan.

35. In addition to low permeability at the surface, it is evident that the embankment contains layers or lenses of low permeability material at depth in the fill. Several small slope failures in the face of the partially completed embankment were observed during the January 28, 2002 site inspection. The exposed face of the embankment, shown at one location in the photograph in **Exhibit J**, revealed layers of low permeability material which impede the downward movement of water and which can be expected to contribute to a faster lateral subsurface stormwater response than assumed by the Port.

36. The Port's analysis of the impacts of embankment construction relies on linking the HSPF hydrologic model with more detailed (and more appropriate) analysis of groundwater movement through the fill embankment using Hydrus and Slice models. The general approach has been for the Port to compute hydrologic inputs to the embankment using HSPF, to determine and route the groundwater component of flow through the embankment using the Hydrus model, to determine seepage flows from the embankment and recharge to deep aquifers using Slice, and

then to incorporate those seepage and recharge amounts back into the watershed-scale HSPF model to determine flows in the Miller Creek and Walker Creek receiving waters.

37. This overall approach to predicting groundwater impacts was first described in detail in the August 2001 report "Port of Seattle Sea-Tac Third Runway Embankment Fill Modeling" by Pacific Groundwater Group (PGG). In comparing observed embankment runoff data from February 1999 with predicted runoff data inferred from predicted groundwater recharge, PGG (page 4) stated that differences "*between the observed and predicted runoff may be related to stage measurement or reporting error, stage data interpretation, surface treatments of the Phase I fill that promoted runoff (the fill was bare and compacted at the time), and/or inaccuracies in prediction of hydraulic conductivity based on soil texture.*" It was then concluded (page 5) that "*the fill as a whole is unlikely to exhibit runoff characteristics consistent with the 1999 data*". In other words the observed runoff data, the only data available for directly assessing embankment hydrologic response, was rejected in favor of theoretical infiltration rates.

38. While details of the low flow analyses have been modified as described in the recent December 2001 Low Flow Plan, the basic approach to estimating groundwater inputs to the embankment and the assumed infiltration capacity remain unchanged and treatment of pervious areas in the low flow analysis remains inconsistent with the observed hydrologic characteristics of embankment fill. As noted above, HSPF was used to provide hydrologic input to more detailed Hydrus/Slice modeling of groundwater movement in the fill embankment. The HSPF model of pervious embankment areas assumed outwash soils with a grass cover, i.e. highly permeable freely draining soils which produce minimal surface runoff and large

groundwater inputs. The HSPF infiltration parameter INFILT for outwash grass is 0.8 inches/hr, or forty times greater than the value of 0.02 inches/hr determined by calibration to runoff data from the 1998 embankment fill. The characterization of the embankment pervious areas in HSPF as outwash grass is inconsistent with actual quantitative and qualitative observations of the embankment's hydrologic response.

39. The net result of the assumption of outwash soils in HSPF modeling is complicated by the Hydrus model assumption of a saturated hydraulic conductivity for the embankment fill matrix of 1.35 x 10^{-4} cm/sec. (This figure translates into a bulk saturated conductivity for the embankment after correction for gravel content of about 0.65 x 10^{-4} cm/sec or about 0.08 inches/hr). This figure is much closer to our expectations of actual embankment characteristics. In principle, the HSPF model inputs to Hydrus in excess of hydraulic conductivity should appear as surface runoff and not actually contribute to groundwater. However examination of model results indicates that the Hydrus model may not be effectively limiting HSPF groundwater inputs. Table 3.1 of Appendix B of the Low Flow Plan **(Exhibit K)** shows volumes of runoff available for infiltration and volumes actually infiltrated in the Hydrus model. Data for Other Pervious Areas (OPA) are perhaps the simplest to examine since these are pervious embankment areas not affected by run-on from the runway impervious surfaces. For the period of analysis presented in the Low Flow Plan, data in Table 3.1 for the OPA shows 29,689,341 cubic feet of water available for infiltration with about 6% (1,652,948 cubic feet) appearing as (surface) runoff, and the remaining 94% infiltrating and contributing to the groundwater supply.

40. This figure of only about 6% runoff is inconsistent with the both the observed runoff data from the 1998 embankment fill and with the qualitative field observations of January 2002. I examined this issue further by using the calibrated HSPF model parameters from the 1998 fill (provided in paragraph 28) and modeling groundwater inputs to the embankment with HSPF at a one-hour time step for the period 1948 through 1996. The results showed on average that only about 31% of total runoff (i.e. rainfall less evapotranspiration) appeared as groundwater input. When the embankment infiltration rate was increased from the calibrated value of 0.02 inches/hr to 0.08 inches/hr, the percent of runoff appearing as groundwater inputs increased to 68%, still far less than the value implied by Low Flow Plan, Appendix B, Table 3-1.

41. The available data suggest that actual embankment infiltration rates may be less than assumed by the Port. The implication of lower than predicted infiltration rates is that the embankment will produce more surface and shallow subsurface runoff than predicted, with a corresponding reduction in base flow contributions to Miller Creek and Walker Creeks, and hence a reduced ability to offset the low flow impacts of proposed projects. It is evident that there is considerable uncertainty with regard to the hydrologic characteristics of the proposed embankment. The effects of such uncertainty have not been addressed by the Port.

42. Additional issues related to the application of the linked HSPF and Hydrus/Slice models to assess low flow impacts are addressed by my colleague Bill Rozeboom in his testimony in this case.

Monitoring and Contingency Measures

43. Uncertainty in the hydrologic response of the proposed embankment can only be satisfactorily resolved through monitoring of rainfall on and runoff from a section of completed or largely completed embankment. The embankment section would ideally be grassed and in as close to its final condition as possible. Reliable characterization of the embankment runoff is necessary to accurately predict the hydrologic impacts of embankment construction and to assure the design of appropriate and functional mitigation measures.

44. The Low Flow Plan makes reference (Low Flow Plan, Section 5.3.2) to determining embankment infiltration capacity using Pilot Infiltration Tests (PITs) which would involve determining infiltration rates under saturated conditions by measuring the rate at which water must be added to maintain a constant water level in small ponds (with about a 100 ft^2 footprint) constructed on the top of the embankment. While such tests are an improvement over standard infiltrometer tests, they are intended to provide information on infiltration rates for the design of stormwater infiltration ponds, which operate under saturated ground conditions and which the test environment seeks to mimic. The Pilot Infiltration Tests cannot be expected to conform to or replicate the unsaturated subsurface conditions with which we are concerned in determining embankment runoff and infiltration during periodic rainfall events. In short, the proposed infiltration tests are a poor substitute for direct measurement of embankment runoff.

45. The proposed infiltration testing (Low Flow Plan, Section 5.3.2) is for up to eight locations including, apparently, infiltration tests in the areas of "pavement subgrade" and

"pavement support". The relevance of tests at those particular locations to low streamflow analyses is unclear, since presumably those areas would be paved on completion of the runway.

46. I note also that (Low Flow Plan, page 5-9) "*shallow excavations may be used*" to perform infiltration tests. If low surface permeability is indeed a feature of the constructed embankment, as appears to be the case from field observations, then infiltration tests in shallow excavations will not be representative of actual as-built conditions.

47. The December 2001 Low Flow Plan appears to acknowledge the uncertainty in characterization of embankment hydrology through its discussion of contingency measures in the event that the constructed embankment infiltration rates are lower than predicted (Low Flow Plan, Section 5.3.5). The plan (page 5-11), however, only makes non-specific reference to interpreting long-term monitoring data to allow the Port *to "adapt water management practices to the as-built conditions*". This does not provide reasonable assurance for the 401 Certification that stream flows will be maintained.

Concluding Remarks

48. In conclusion, it is my opinion that the hydrologic models which form the foundation for identification and design of stormwater and low flow mitigation measures for the proposed projects are deficient in either their calibration or their representation of the physical features of the various watersheds within the project area. The HSPF hydrologic models for Walker Creek and Des Moines Creek in particular are poorly calibrated. Simulation results for Walker Creek strongly suggests a lack of understanding of hydrologic processes in this basin

which adversely affects the ability to simulate both flood flows and low flows. For Des Moines Creek, the ability to simulate low flows is especially poor and again indicates a lack of understanding of important hydrologic processes. With the current deficiencies, there can be no assurance that mitigation measures proposed to date will meet their intended performance standards of preserving flows in the affected streams.

49. In my opinion, considerable uncertainty remains as to the hydrologic response of the proposed fill embankment. There appears to be significant uncertainty in prediction of the as-built infiltration rates for the embankment and a corresponding lack of reasonable assurance that the embankment will perform as needed to ensure mitigation of low flow impacts in Walker and Miller Creeks.

DATED this 22 day of February 2002, at Seattle, Washington.

K.M. Leytham, Ph.D., P.E.

Pre-Filed Testimony
of
Dr. Malcolm Leytham

INDEX TO EXHIBITS

A. Curriculum Vitae of Dr. Dr. Malcolm Leytham

B. Figure B2-41 from Appendix B to the July 2001 Stormwater Management Plan update comparing observed and simulated streamflow in Walker Creek

C. Stormwater Management Plan, Appendix B, Figure B2-2 to the July 2001 update, "Groundwater Flow Direction and Boundaries"

D. December 2001 Low Flow Plan, Figure (unnumbered) "Change between Existing (1994) and Future (2006) Groundwater Basins"

E. December 2001, Low Flow Plan figure s 3-5 and 3-6 Low Flow Calibration review

F. December 2001 Stormwater Management Plan, Appendix B, figure B2-9, "Observed vs. Simulated Stream Flow Miller Creek at RDF

G. December 2001 Low Flow Plan Figure 4-11, Low Flow Calibration Review

H. December 2000 Stormwater Management Plan Appendix A unnumbered figure HFAM Output February 1999

I. Photographs of standing water on the fill embankment, 28 January, 2002

J. Photograph of failure in the fill embankment, 28 January 2002

K. December 2001 Low Flow Plan, Appendix B, Table 3-1 embankment modeling report

A

K.M. LEYTHAM, Ph.D., P.E.

EDUCATION

B.Sc. in Civil Engineering, University of Birmingham, U.K., 1971

S.M. in Water Resources, Massachusetts Institute of Technology, 1974

Ph.D. in Hydrology, University of Washington, 1982, specialized in stochastic modeling of large scale droughts.

GENERAL

Dr. Leytham has wide experience as an engineering hydrologist primarily with specialist consulting engineering organizations. He has worked on projects throughout North America and in South America, the Caribbean and the Far East. He has particular expertise in the analysis and synthesis of hydrologic data and in the development and application of catchment hydrology models for such uses as estimation of design floods, for flood forecasting, for seasonal snowmelt forecasting, and for the design of urban stormwater management facilities.

CHRONOLOGICAL EXPERIENCE

January 1987 - Present: Principal with Northwest Hydraulic Consultants. Responsible for hydrology studies in the Seattle office.

March 1986 - December 1986: Senior Hydrologist with Northwest Hydraulic Consultants. Responsible for hydrology studies in the Seattle office.

August 1985 - March 1986: Senior Hydrologist with Ott Water Engineers Inc., Bellevue, Washington. Responsible for hydrology studies in the Northwest regional office.

January 1983 - August 1985: Self-employed consultant providing services primarily in the area of deterministic catchment modeling and the development of computer models for flow forecasting.

May 1982 - January 1983: Senior Hydrologist with Crippen Consultants Inc., Seattle, Washington. Responsible for hydrology work related to hydropower developments.

September 1979 - May 1982: Ph.D. program at the University of Washington. Research into the stochastic generation of multi-site precipitation data for modeling large-scale droughts.

August 1975 - May 1979: Hydrologist with Hydrocomp Inc., Palo Alto, California. Involved in a wide variety of hydrology projects, including development of simulation models, catchment hydrology studies and analysis of hydrologic and meteorologic data.

SELECTED PROJECT EXPERIENCE

PMF Studies for Travers and McGregor Dams: Conducted a probable maximum flood study for Travers and McGregor Dams in the Carseland – Bow River Headworks system of southern Alberta.

Snohomish County Drainage Needs Reports: Hydrology technical lead for County-wide analyses of storm drainage problems and development of capital improvement projects for Snohomish County, Washington. Developed hydrology protocols to ensure County-wide consistency of study approach, and resolved technical problems in hydrologic and hydraulic analyses over the course of the study.

Dai Ninh Hydroelectric Project: Hydrology specialist for review and update of hydrologic data for the final design of the Dai Ninh Hydroelectric Project, Vietnam.

Mullen Slough CIP Study: Project manager for HSPF hydrologic modeling of the Mullen Slough basin in south King County, Washington. The basin has a history of flooding associated with urban development. Multiple scenarios were modeled to determine the impacts of alternative land use on stream flows and to evaluate alternative approaches to storm water management.

Lewis River Project Relicensing Studies: Project manager for flood management aspects of relicensing studies for Swift, Yale, and Merwin Dams on the Lewis River, Washington. Investigated the flood management benefits of alternative project operating policies, including development of inundation maps for the Lewis River from Merwin Dam downstream to its confluence with the Columbia River (ongoing).

Kelsey Dam Safety Review - Hydrologic and Hydraulic Aspects: Participated in the hydrologic and hydraulic aspects of a dam safety review for Kelsey Generating Station on the Nelson River, Manitoba. Responsible for reviewing estimates of the Inflow Design Flood.

Travers Dam PMF Review: Undertook a comprehensive review of the PMF estimated for Travers Dam on the Little Bow River, Alberta.

Mill Creek, Salem, Flood Reduction Study. Project manager for development of hydrologic and hydraulic models of Mill Creek, Salem, Oregon for use in the investigation of system improvements to reduce urban flooding through the city of Salem. Hydrologic modeling was done using HEC-HMS. Hydraulic modeling was done using an unsteady flow UNET model to represent complex multiple flow breakouts, flow splits, and flood storage facilities. Both models were calibrated to data from the major flood of February 1996.

Nechako Reservoir Inflow Analysis. Directed analyses of inflow data for Nechako Reservoir, British Columbia, to determine the best way of forecasting average annual inflows for a reservoir expansion study. The current record of inflows exhibits a cyclicity with inflows above or below the long-term average for extended periods of time. The analysis found a relatively strong relationship between reservoir inflows and the Pacific Decadal Oscillation (PDO), a long-lived (decadal) bimodal pattern of climate variability in the North Pacific. Estimates of average reservoir inflows for an approximately 25 year planning horizon were provided on the basis of a recent phase change in PDO.

Black Butte Dam Rainfall-Runoff Model and PMF Estimate. Project manager for development of a HEC-HMS rainfall-runoff model of the Stony Creek basin above Black Butte Dam, Northern California. The calibrated model was subsequently used to develop Probable Maximum Flood (PMF) estimates at the dam site. Probable Maximum Precipitation (PMP) estimates used as input to the PMF analysis were obtained from the National Weather Service HMR58 guidelines.

Masonry Dam Flood Control Operations Study: Project manager for the investigation of alternative flood control operating policies for Masonry Dam on the Cedar River, Washington. Work included development of alternative operating policies and assessment of the impacts of those policies on flood damage, hydropower generation, water supply safe yield, and downstream fisheries production.

Shillapoo Lake Ecological Restoration: Project manager for hydrologic and hydraulic studies for the proposed restoration of Shillapoo Lake, an approximately 900-acre area in the Columbia River floodplain, Washington. Analyzed alternative means for re-establishing hydraulic connections between Shillapoo Lake and the Columbia River to restore ephemeral wetland conditions. Produced conceptual level designs for the preferred alternative including: levees, water control structures, conveyance systems, and pump station.

South Heart River Dambreak Studies: Directed the performance of dambreak simulations using the U.S. National Weather Service FLDWAV model to determine the required spillway capacity of a dam on the South Heart River, Alberta, under the Incremental Hazard Evaluation methodology.

Walker River Hydrology Studies: Project manager for comprehensive hydrologic studies of the Walker River Basin; a 4,000 square mile closed basin in eastern California and western Nevada.

Seven Mile Dam PMF Review and Characterization of Extreme Floods: Reviewed the PMF for Seven Mile Dam on the Pend Oreille River, British Columbia and performed detailed flood frequency analyses to estimate the magnitude and frequency of extreme floods for use in risk analyses undertaken by others.

Lewis River Flood Study: Project manager for an investigation of the severe flooding which occurred in February 1996 along the Lewis River, Washington, downstream from Merwin Dam. Work involved field identification of high water marks, reconstruction of natural (i.e. unregulated) flows, development of a hydraulic model of the Lewis River from the dam to its confluence with the Columbia River, and determination of flood profiles and areas of inundation for actual and hypothetical project operations.

Iron Gate PMF Study: Project manager for the determination of the probable maximum flood at Iron Gate Dam on the Klamath River, California.

Lake Chelan Hydroelectric Project PMF: Project manager for the determination of the probable maximum flood for the Lake Chelan Hydroelectric Project on the Chelan River, Washington.

Juri River Flood Warning System: Provided advice and assistance in the evaluation of a low-cost flash flood warning system on the Juri River in northeastern Bangladesh. The work involved the design and implementation of a network of rainfall and streamflow gauges, analysis of hydrometeorologic data, and conceptual level design of the flood warning system and flood disaster management program.

Snoqualmie Ridge Parkway: Reviewed the design of temporary erosion control facilities for the construction of the Snoqualmie Ridge Parkway, Washington.

Evaluation of Rainfall - Runoff Models: Conducted an evaluation of rainfall-runoff models for the Northwest Region, National Rivers Authority, U.K.. The study included an interview program with agency staff to determine needs, review of models potentially suitable for adoption by the agency, and test case application of selected models to several catchments.

Mill Creek (Auburn) Flood Control Plan: Technical lead for the development of the Mill Creek Flood Control Plan, a multi-objective, multi-jurisdictional effort to develop and implement a comprehensive flood control and environmental restoration plan for the Mill Creek Basin, Auburn, Washington. As technical lead, managed all technical input to the project, provided direction to and coordinated the work of wetland, fisheries, water quality, and hydraulic and hydrologic modeling specialists, developed and analysed conceptual flood control alternatives consistent with the project's environmental goals, provided technical liason with project stakeholders, and advised on stakeholder selection of a preferred flood control alternative.

North Umpqua River Flow Forecasting Model: Project manager for the development of seasonal and short-term flow forecast models for use in the operation of hydro-electric generation facilities on the North Umpqua River, Oregon.

Hydrologic Analysis and Modeling for Remedial Works on Mt. Pinatubo: Project manager for development of hydrometeorologic database and estimation of design flows for use in the planning and design of sediment and flood control measures on the eight major water courses affected by the 1991 eruption of Mt. Pinatubo, Philippines.

Northridge Master Drainage Plan: Project manager for the conceptual design of stormwater management facilities for a proposed 1500 acre mixed-use (commercial and residential) development in King County, Washington.

Beaverdam Master Drainage Plan: Project manager for hydrologic monitoring, hydrologic analysis, and conceptual level design of stormwater control facilities for a residential golf course development in an environmentally sensitive area in western King County, Washington.

Snoqualmie Ridge Master Drainage Plan Review: Project manager for detailed technical review of the analysis and design of stormwater control facilities for a proposed 1300 acre mixed use development in the City of Snoqualmie, Washington.

Small-Scale Flood Control Structure Operation and Maintenance Mission: Participated in a mission to design and develop a program for improving the operation and maintenance of small-scale flood control structures throughout Bangladesh.

Mill Creek Upper Detention Pond Operation Study: Conducted hydrologic studies to develop an optimal operating policy for a regional stormwater detention facility at the head of Mill Creek Canyon, Kent, Washington.

Sammamish River Multi-Objective Corridor Management Plan: Project manager for hydraulic modeling aspects of a study to enhance fishery and recreational use of the Sammamish River corridor, King County, Washington. Responsible for developing a water surface profile model for the river and for evaluating the effects of proposed environmental enhancements on flood levels along the river corridor.

East Side Green River Drainage Study: Project manager for hydrologic modeling aspects of a study to alleviate local flooding associated with the East Side Green River drainage system in the lower part of the Green River valley, Washington.

BWDB/CIDA/AIT Training Course: Developed and taught the hydrology component of a two-month training course for water resources engineers from the Bangladesh Water Development Board.

Issaquah Creek HSPF Model Calibration: Project manager for calibration of an HSPF hydrologic simulation model to streamflow and rainfall data from the Issaquah and Tibbetts Creek catchments in King County, Washington.

City of Lynnwood Flood Plain Mapping Study: Project manager for a flood plain mapping study on Scriber Creek in the City of Lynnwood, Washington.

City of Lynnwood Stormwater Modeling: Performed detailed hydrologic analyses of stormwater runoff in the City of Lynnwood, Washington.

Highwood River/Little Bow River PMF Study: Conducted hydrologic modeling and dambreak analyses for estimation of the probable maximum flood and the spillway design flood for a proposed dam on the Little Bow River, Alberta. The PMF is generated by a major flood on the neighboring Highwood River, which spills over a low topographic divide into the headwaters of the Little Bow River. Dambreak simulations were performed using the U.S. National Weather Service DAMBRK model.

Kent Lagoons Hydraulic Design: Project manager for the conceptual hydraulic design of a regional off-channel stormwater detention facility in Kent, Washington.

Miller Creek Regional Stormwater Detention Facility Design: Performed hydrologic modeling for the design of two regional stormwater detention facilities in the Miller Creek basin, King County, Washington.

Lilliwaup Creek Hydropower Review: Reviewed power production potential of a small hydropower facility on Lilliwaup Creek, Washington.

Scriber Creek Watershed Management Plan: Project manager for hydrologic modeling (using the EPA's HSPF continuous simulation model) for the Scriber Creek Watershed Management Plan, Snohomish County, Washington. Work included model calibration, simulation of flows for future land-use conditions, and simulation and analysis of various strategies for stormwater control in this rapidly developing suburban watershed.

Small Scale Water Control Structures: Developed hydrologic criteria to meet both engineering and agro-economic goals for the design of small scale water control structures in Bangladesh.

Surface Water Design Manual Review: Project manager for detailed technical review of proposed design manual for surface water and stormwater management facilities to be built in King County, Washington.

Tony Creek Hydrology Study: Conducted hydrologic studies for the design of a small hydropower plant on Tony Creek, Montana.

Mill Creek Regional Stormwater Detention Study: Project manager for a detailed study of a proposed regional off-channel stormwater detention facility in Kent, Washington, including collection of hydrologic data, hydrologic modeling (using EPA's HSPF model), and analysis of the system's performance.

Black and Fannegusha Creek Watersheds Hydrologic and Hydraulic Analyses: Project manager for hydrologic and hydraulic studies on Black and Fannegusha creeks, Mississippi for the design and evaluation of a system of flood water retarding structures.

Clear Creek Hydrology Study: Performed field work and hydrologic analyses for a fish farm on Clear Creek, Washington to identify and document the causes of high stream turbidity believed to have resulted from upstream urban development.

Licorice Fern Stormwater Management and Erosion Control Study: Project manager for conceptual design of stormwater management and erosion control facilities for a 170-acre residential development on steep terrain in King County, Washington.

Skagit River Flood Forecast Model: Project manager for the development of a flood forecast model for the Upper Skagit River basin, Washington.

Wabamun Lake Water Level Simulation Study: Developed monthly water balance model of Wabamun Lake, Alberta, and performed long-term simulation of lake levels to evaluate various proposed modifications to the lake outlet control structure.

Lake Washington Basin Runoff Model: Project manager for development of a daily water balance model for Lake Washington.

Leach Creek Hydrology and Geomorphology Study: Performed hydrologic studies on Leach Creek, Washington to document the effects of urban development on the stream's hydrologic regime and to identify the causes of severe stream bank and bed erosion.

Washington Basin Climatic Data Base: Project manager for the development of a data base of daily and monthly hydrologic and climatic data for Lake Washington and the surrounding area.

Similkameen River Flood Control Study: Project manager for a flood study for a proposed dam on the Similkameen River, Washington.

Dissolved Nitrogen Modeling for the Columbia and Snake Systems: Developed a system simulation/optimization model for deriving reservoir operating policies which would minimize nitrogen supersaturation levels below 13 major dams on the lower Snake and Columbia rivers while meeting power production constraints.

Veazey Quarry Master Drainage Plan: Project manager for the conceptual design of stormwater and sediment control facilities for a major rock quarry in Washington.

Nisqually River PMF Study: Project manager for the estimation of probable maximum floods at Alder and LaGrande dams on the Nisqually River, Washington.

Snowmelt Forecasting for the Skokomish, Cowlitz and Nisqually Rivers: Developed and implemented a seasonal snowmelt forecasting model for the operation of hydroelectric generation facilities on the Skokomish, Cowlitz and Nisqually rivers, Washington.

Surface Water Appraisal Study: Conducted a field appraisal of surface water supply potential for a resort development on the island of Lanai, Hawaii.

Coal Creek Basin Plan: Provided advice and assistance in the application of an HSPF hydrologic simulation model for the development of the Coal Creek Basin Plan. Responsible for designing the overall modeling approach, directing model calibration, providing training, and assisting in the design and interpretation of production runs for future land use scenarios.

Green River Low Flow Study: Managed a study to develop alternative low flow operating policies for the Hanson Dam on the Green River, Washington, to enhance downstream water quality and fisheries.

Strategies for Coping with Drought: Participated in research into the effect of drought on hydro- and thermal-electric power production. Developed techniques for evaluating the spatial characteristics of widespread drought.

Flood Forecasting for the Salt and Verde Rivers, Arizona: Developed and implemented a real-time flood forecasting model for the operation of a system of reservoirs on the Salt and Verde rivers in Arizona.

Iskut River PMF Study: Estimated the probable maximum flood for three dams on the Iskut River in northern British Columbia. Special consideration was required for runoff from heavily glacierized areas of the basin.

Hydropower Reconnaissance Studies: Performed numerous hydrologic studies related to the development of small-scale hydroelectric projects on Burlington Northern land holdings throughout the northwestern U.S.A., including estimation of flow duration and flood frequency curves for both gaged and ungaged catchments, preliminary sizing of equipment, and assessment of energy production.

Water Supply Studies for Homer, Alaska: Conducted hydrologic simulation studies to determine the water supply yield of several small streams in the vicinity of Homer, Alaska.

Sunset Falls Hydroelectric Study: Conducted flood studies and conceptual design of flood control works for a proposed hydroelectric project on the South Fork Skykomish River, Washington.

Transmigration Project Village Water Supplies: Conducted reconnaissance level hydrologic studies and yield analyses for village water supplies in Sumatra, Indonesia.

Hurricane Modeling for Probable Maximum Precipitation (PMP) Estimates, Dominican Republic: Developed a computer model of hurricane-generated rainfall for PMP estimates for spillway design studies for dams on the Rio Blanco, Dominican Republic.

Paranaiba River Hydrology and PMF Studies, Brazil: Performed extensive hydrology studies for hydroelectric development on the Paranaiba River, Brazil, including estimation of PMF at three dam sites, stochastic generation of long flow sequences and training of Brazilian personnel.

Sediment Transport Modeling: Developed mathematical models for simulating sediment transport in river systems and for predicting soil loss from agricultural lands.

SELECTED PUBLICATIONS

Jackson C.R., S.J. Burges, X. Liang, K.M. Leytham, et al. "Development and Application of Continuous Hydrologic Modeling for Drainage Design and Analysis." Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas, Water Science and Application 2, American Geophysical Union, Washington DC, 2001.

Karpack, L.M. and K.M. Leytham. "A Simple Short-Term Flow Forecast Model For Small Hydropower Systems." Mountain Hydrology: Peaks and Valleys in Research and Application, Canadian Water Resources Association, 1995.

Peck, H.W., K.W. Eriksen, M.L. Pearson, and K.M. Leytham. "Post Eruption Hydrology and Hydraulics of Mount Pinatubo, The Philippines." Tech. Rep. 9L-94-16, Waterways Experiment Station, U.S. Army Corps of Engineers. May 1994.

Leytham, K.M. "A Joint Rank Test for Assessing Multivariate Normality in Hydrologic Data", Water Resources Research, 23 (12):2311-2317, 1987.

Leytham, K.M., D.P. Lettenmaier and E.G. Altouney. "Widespread Drought and the Hydroelectric Industry", Hydro Review, VI(V):26-31, 1987.

Tangborn,W.V., J.L. Keane and K.M. Leytham. "Application of Streamflow Forecasts to Operating a Multi-Reservoir System in Central Arizona", in A Critical Assessment of Forecasting in Western Water Resources Management, Technical Publication TPS-84-1, American Water Resources Association, 1984.

Leytham, K.M. "Maximum Likelihood Estimates for the Parameters of Mixture Distributions", Water Resources Research, 20(7):896-902, 1984.

Leytham, K.M. "Scale Problems in the Synthesis of Multi-Site Precipitation" in Proceedings of the International Symposium on Hydrometeorology, Denver, CO., June 1982, American Water Resources Association, 1983.

Tangborn, W.V. and K.M. Leytham. "Snowmelt Forecasting for Peak Flow Rates and Runoff Volumes in Mountainous Areas", WMO Technical Conference on Mitigation of Natural Hazards Through Real Time Data Collection and Hydrological Forecasting, Sacramento, CA., 1983.

Leytham, K.M. "Physical Considerations in the Analysis and Synthesis of Hydrologic Sequences" Tech. Rep. No. 76, Charles W. Harris Hydraulics Lab., Dept. of Civil Engineering, University of Washington, Seattle, WA., June 1982.

Leytham, K.M. and D.D. Franz. "Techniques for the Generation of Long Streamflow Sequences" in "Improved Hydrologic Forecasting: Why and How" Proceedings of the Engineering Foundation Conference, Asilomar, CA., May 1979, ASCE, New York, 1980.

Leytham, K.M. and R.C. Johanson. "Watershed Erosion and Sediment Transport Model" Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA, March 1979.

Johanson, R.C. and K.M. Leytham. "Modeling Sediment Transport in Natural Channels" in Watershed Research in Eastern North America: A Workshop to Compare Results, D. Correll, Ed. Chesapeake Bay Center for Environmental Studies, Smithsonian Institute, 1977.

Fleming, G. and K.M. Leytham. "Real-Time Forecasting for Southern California" Symposium on Weather Radar and Water Management, Water Research Centre, Berkshire, England, December 1975.

Leytham, K.M. "A Search Technique for Formulating Improved Water Resource Configurations" in Systematic Approach to Water Resource Plan Formulation, J.C. Schaake Jr., Ed. Tech. Rep. No. 187, Ralph Parsons Laboratory for Water Resources and Hydrodynamics, MIT, July 1974.

PROFESSIONAL AFFILIATIONS

Registered Professional Engineer in the States of Washington and Oregon
Registered Professional Hydrologist, American Institute of Hydrology
American Geophysical Union
American Society of Civil Engineers

B

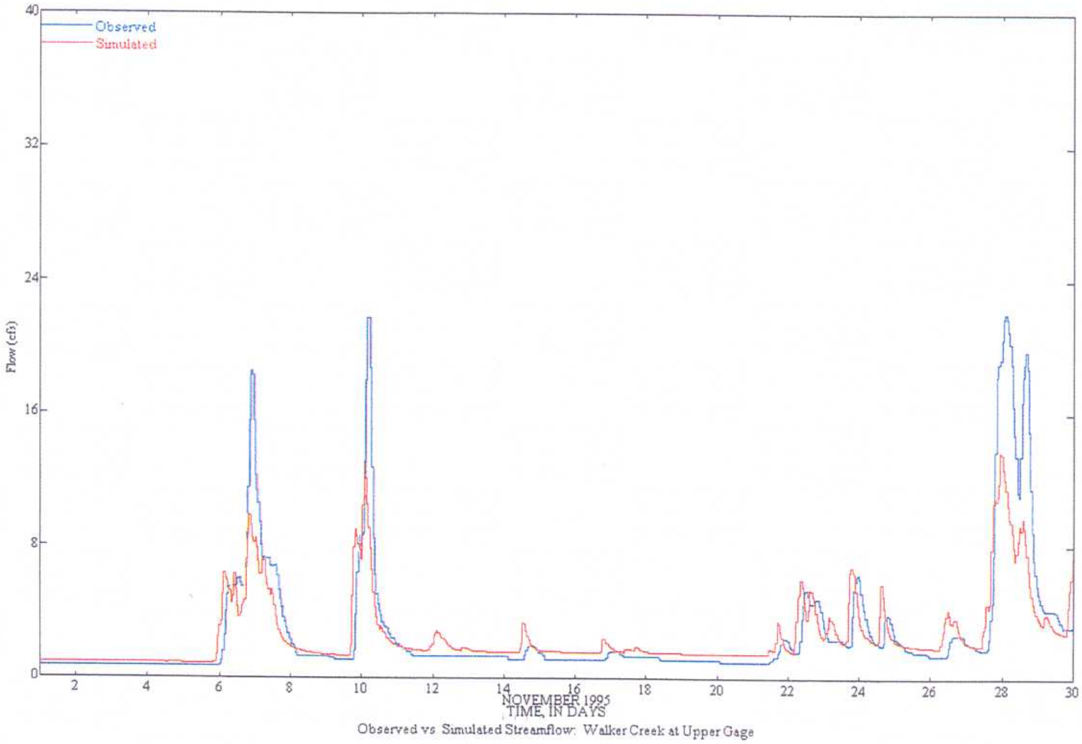
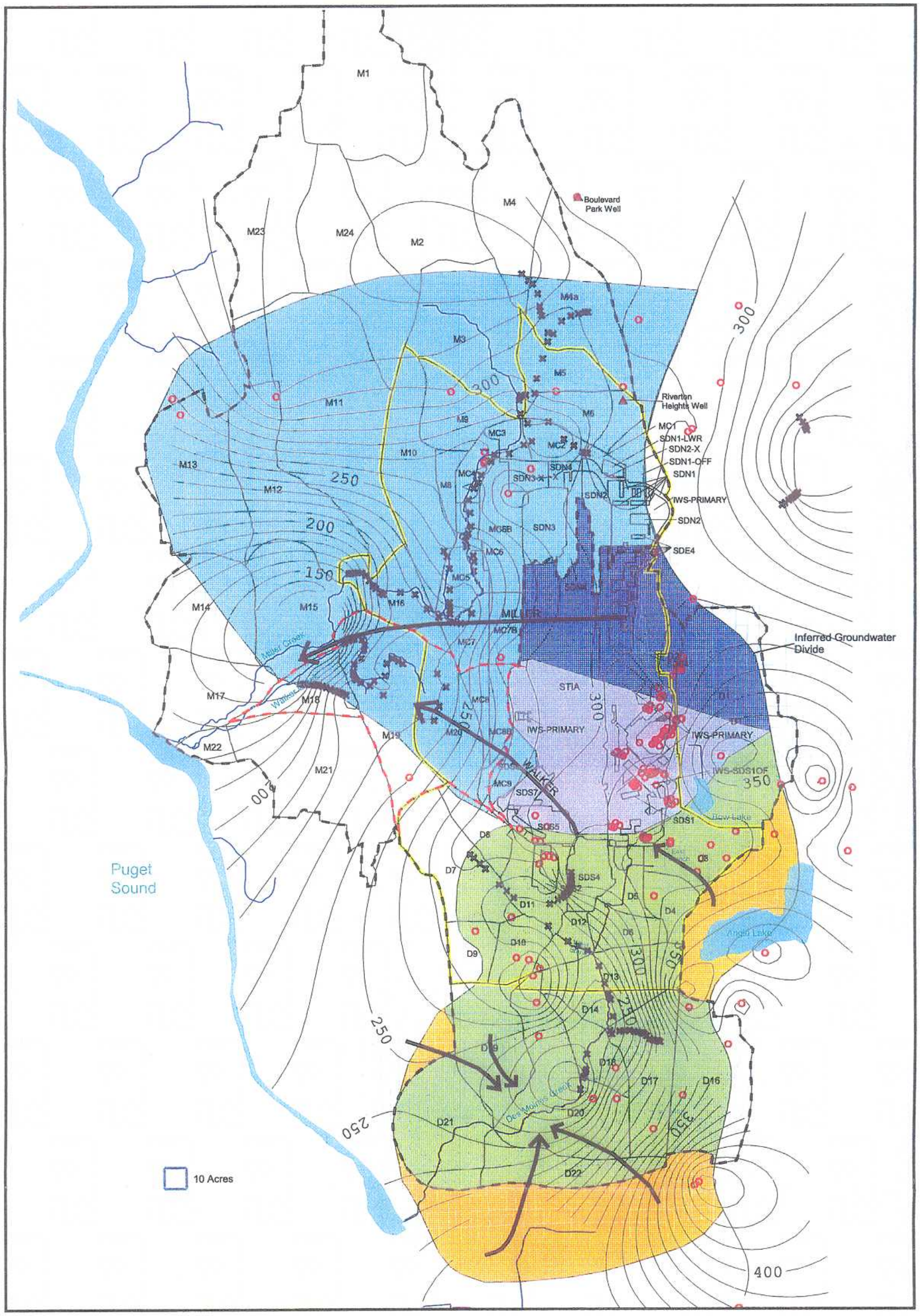

Observed
Simulated
Flow (cfs)
40
32
24
16
8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
NOVEMBER 1995
TIME, IN DAYS
Observed vs Simulated Streamflow: Walker Creek at Upper Gage

Figure B2-41

C



Parametrix, Inc. Sea-Tac Airport Stormwater Management Plan/556-2912-001(28) 7/00 File: K:\Gis\2912\Arcview\rrseatac-apdxa_may2001

Source: Water bodies derived from USGS hypsography data. Ground water contours from Seattle-Tacoma International Airport Ground Water Study. Associated Earth Sciences, Inc., and S. S. Papadopulos & Assoc., 1999.

Note: STIA Subbassin GIS coverage obtained where conditions may change between 1994 and other conditions; subbasin boundaries shown outside of STIA area are for illustration and reference only.

July 2001
556-2912-001 (28)

- Existing (1994) Drainage Subbasins
- STIA Area (see note)
- Watershed Boundary
- Subwatershed Boundaries
- Rivers
- Roads
- Water Bodies
- Noncontiguous Miller Creek groundwater area
- Noncontiguous Walker Creek groundwater area
- Contiguous Miller/Walker groundwater area
- Noncontiguous Des Moines Creek groundwater area
- Contiguous Des Moines Creek groundwater area
- Ground water elevation contour (10 ft. interval) for shallow (C1) aquifer
- ○ Data Point (e.g. monitoring well)
- ▲ Wells
- XXX Locations where ground water elevation intersects stream channel
- ← General ground water flow direction

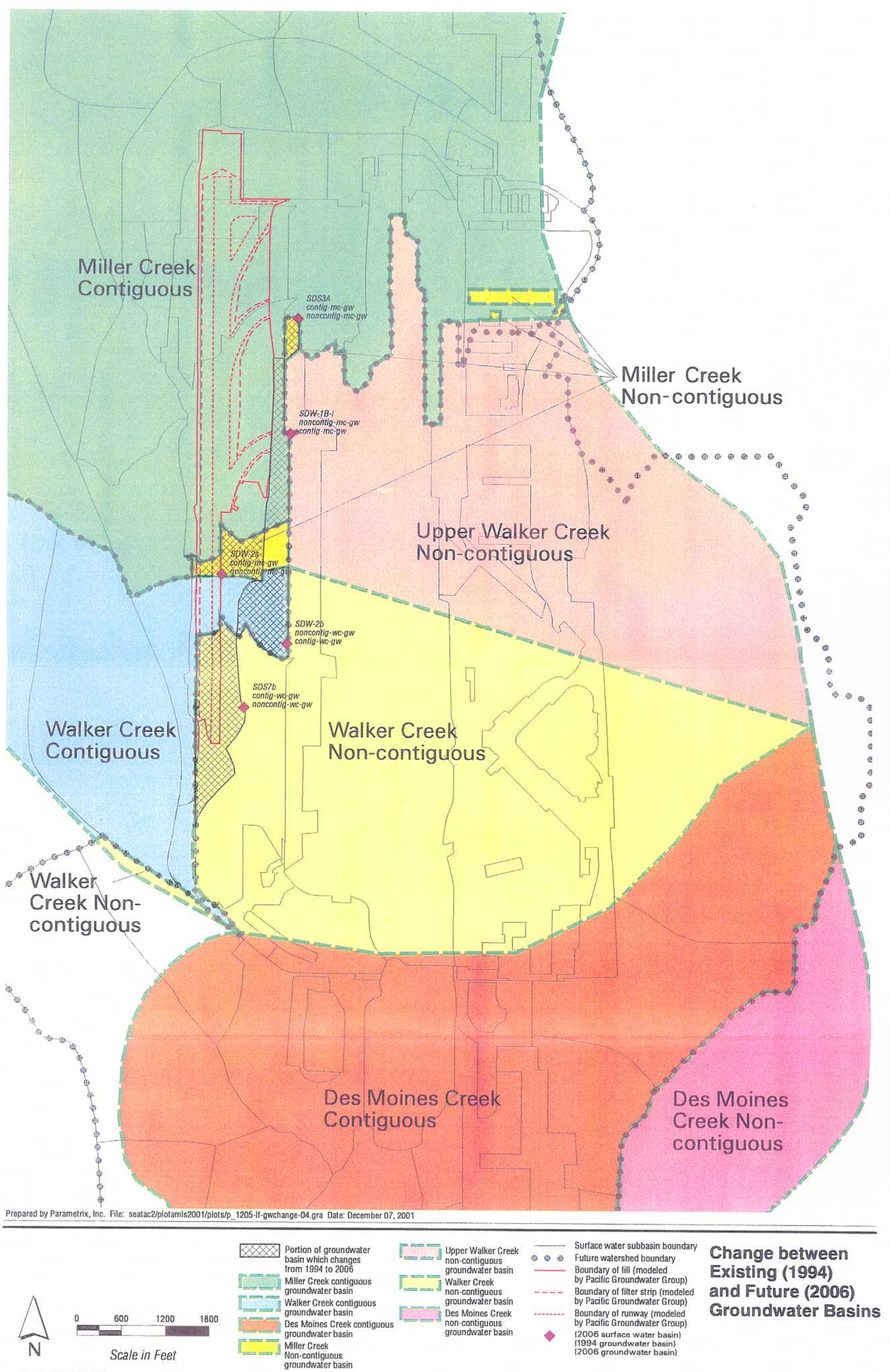
N

1000 0 1000 2000 Feet

1:36,000

Figure B2-2 Groundwater Flow Direction and Boundaries

D



Prepared by Parametrix, Inc. File: seatac2/plotamls2001/plots/p_1205-lf-gwchange-04.gra Date: December 07, 2001

Change between Existing (1994) and Future (2006) Groundwater Basins

www.bluebirdonline.com

E

Figure 3-5. Walker Creek Near Wetland Observed vs. Calibrated Low Flow 1991

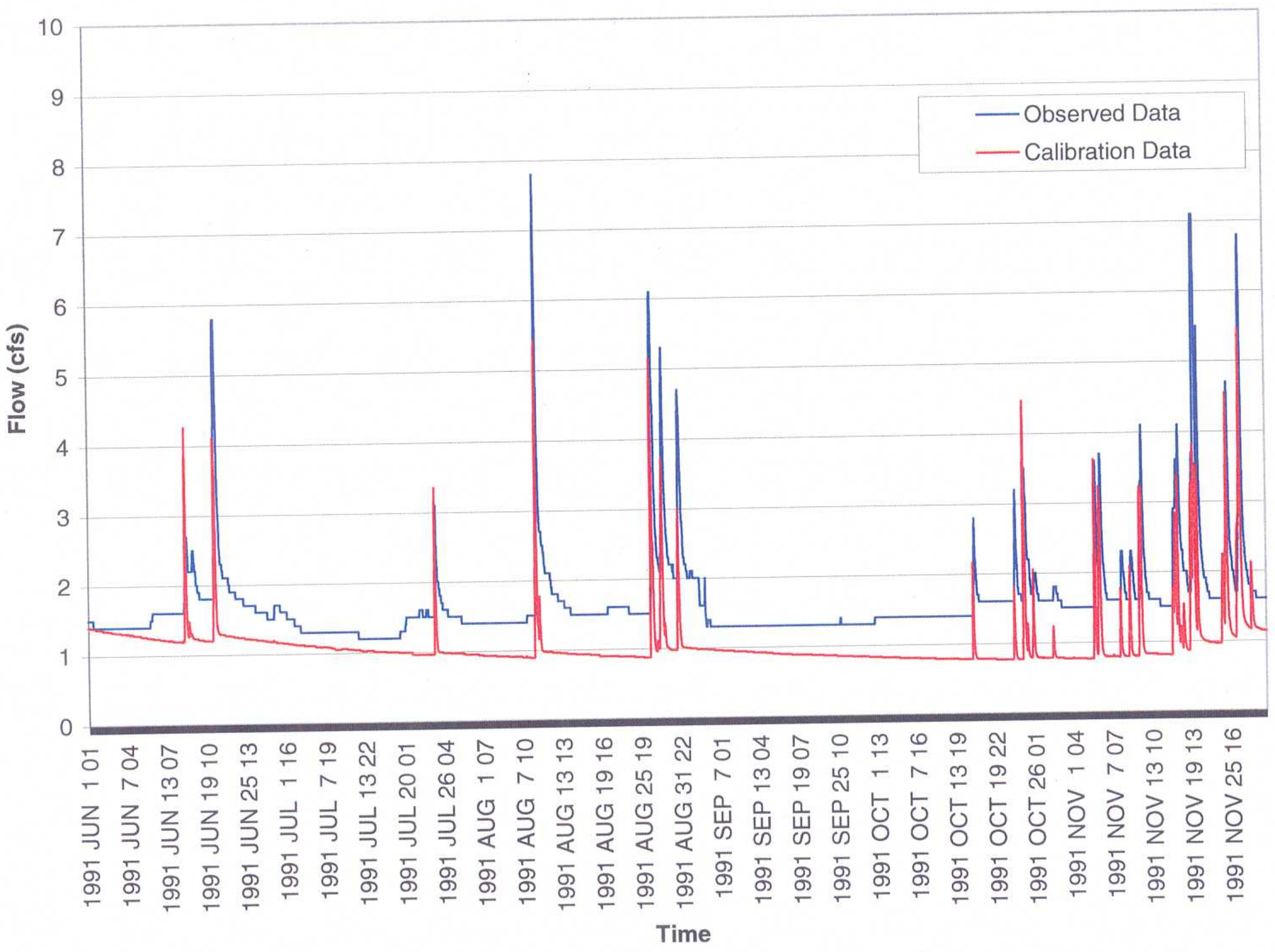
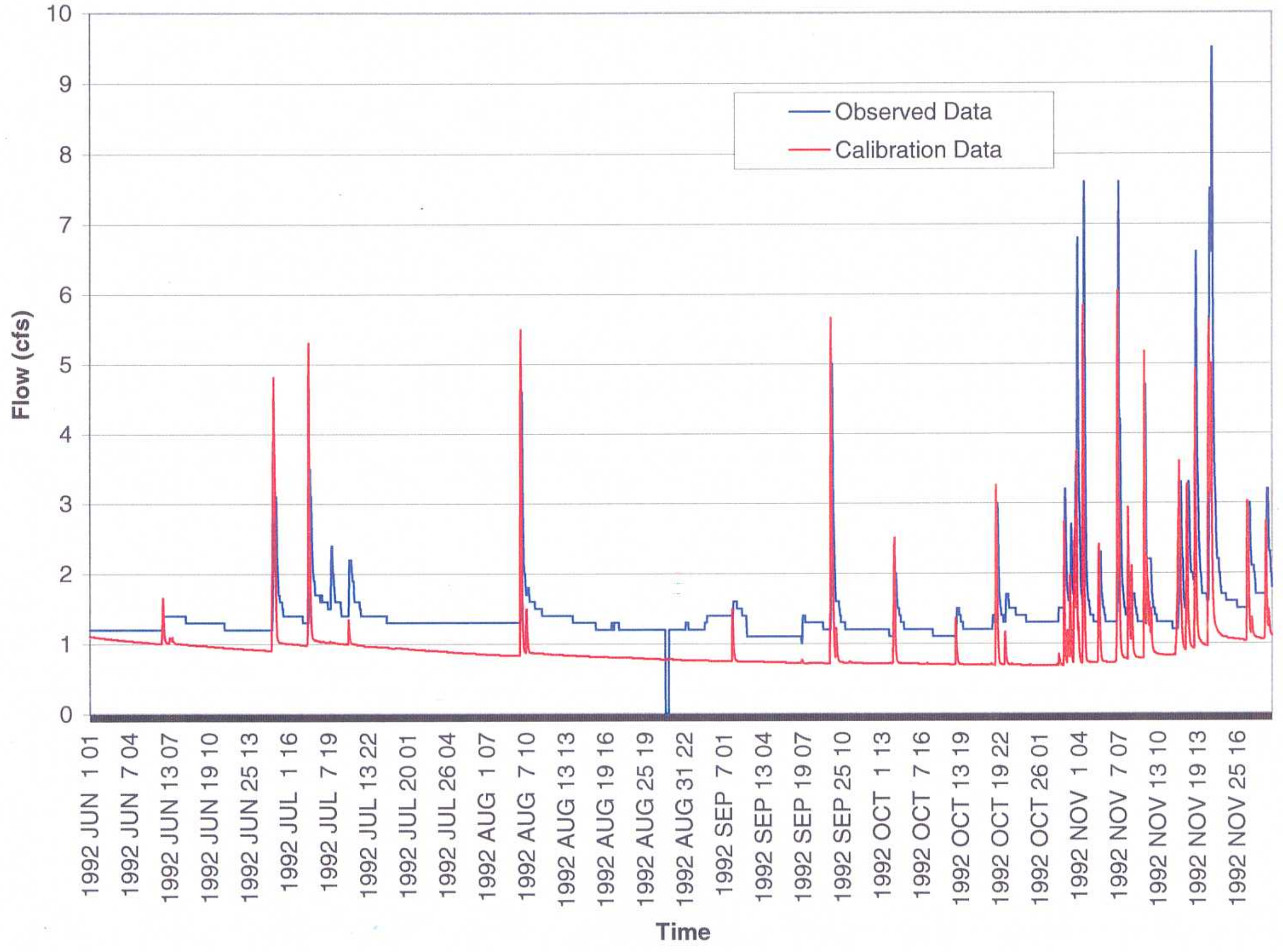


Figure 3-6. Walker Creek Near Wetland Observed vs. Calibrated Low Flow 1992



F

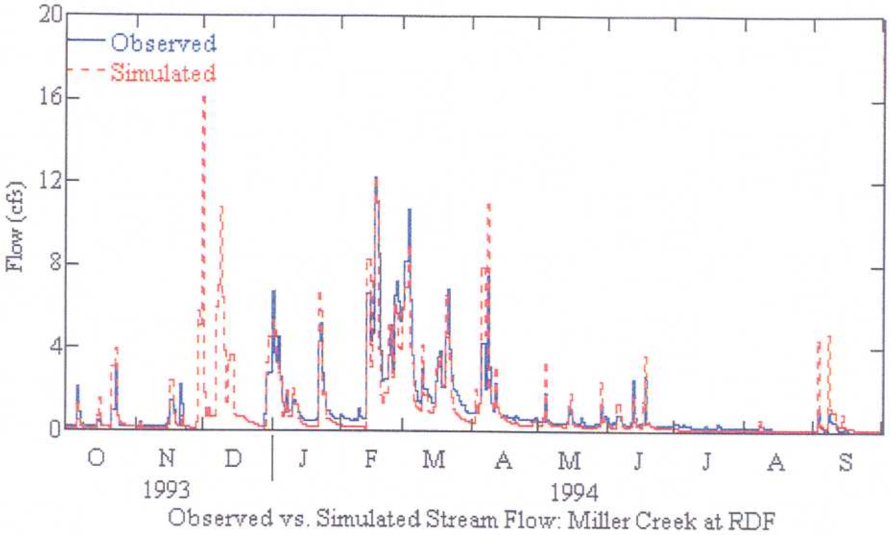
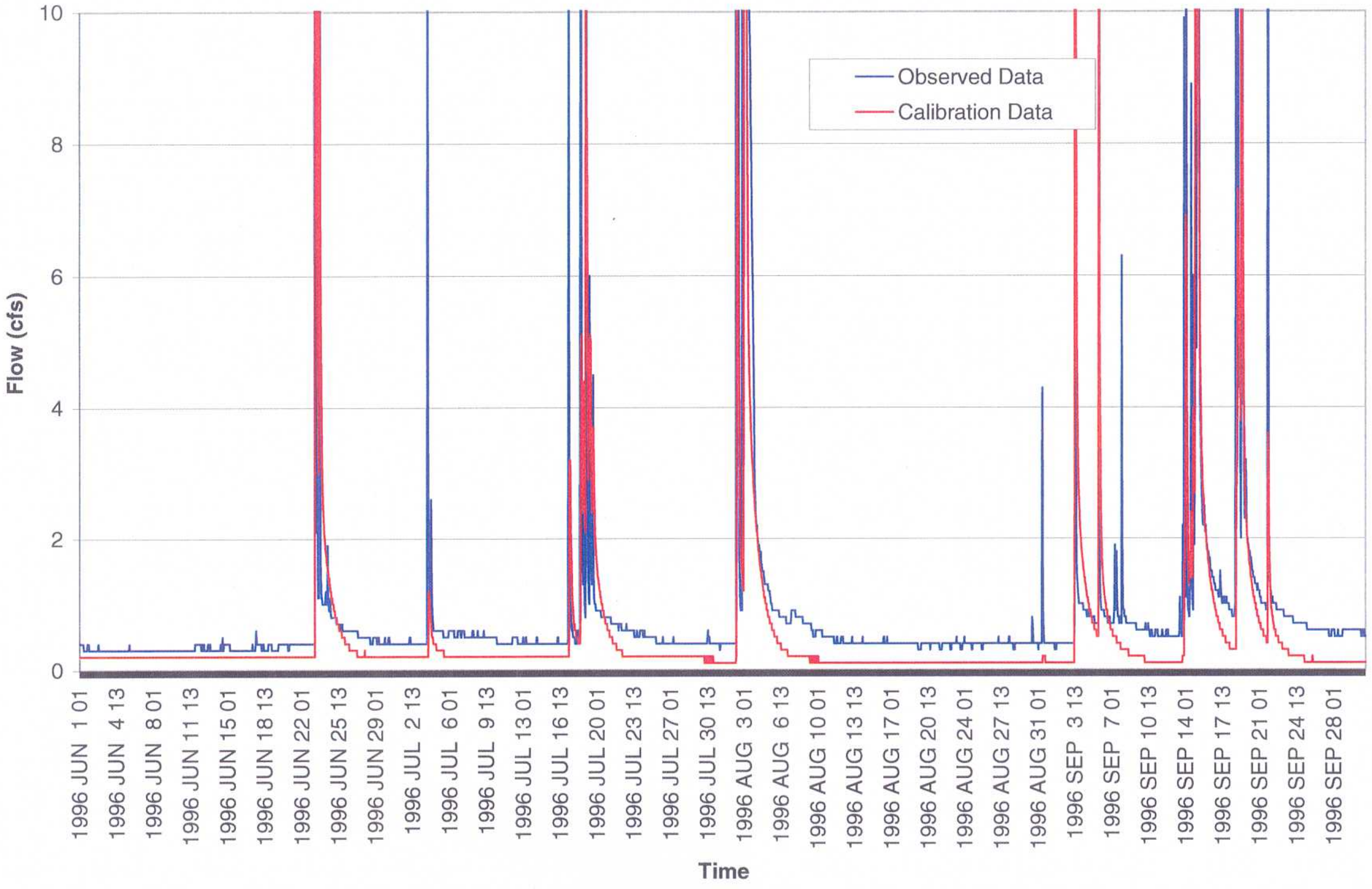

20
16
12
8
4
0
Flow (cfs)
Observed
Simulated
O
N
D
J
F
M
A
M
J
J
A
S
1993
1994
Observed vs. Simulated Stream Flow: Miller Creek at RDF

Figure B2-9

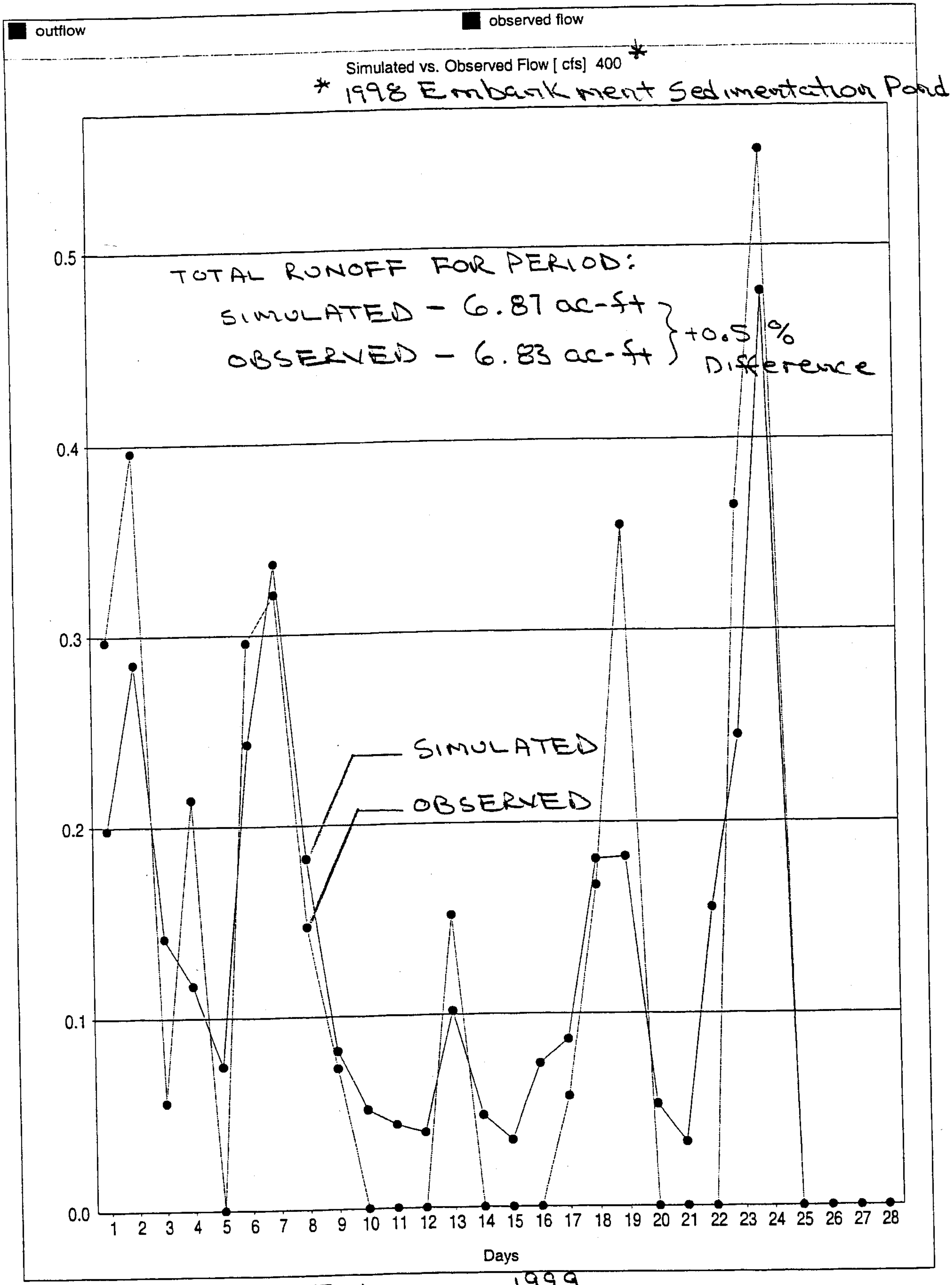
G

Figure 4-11. Des Moines Creek at Gage 11c Observed vs. Calibrated Low Flow 1996



H

HFAM OUTPUT



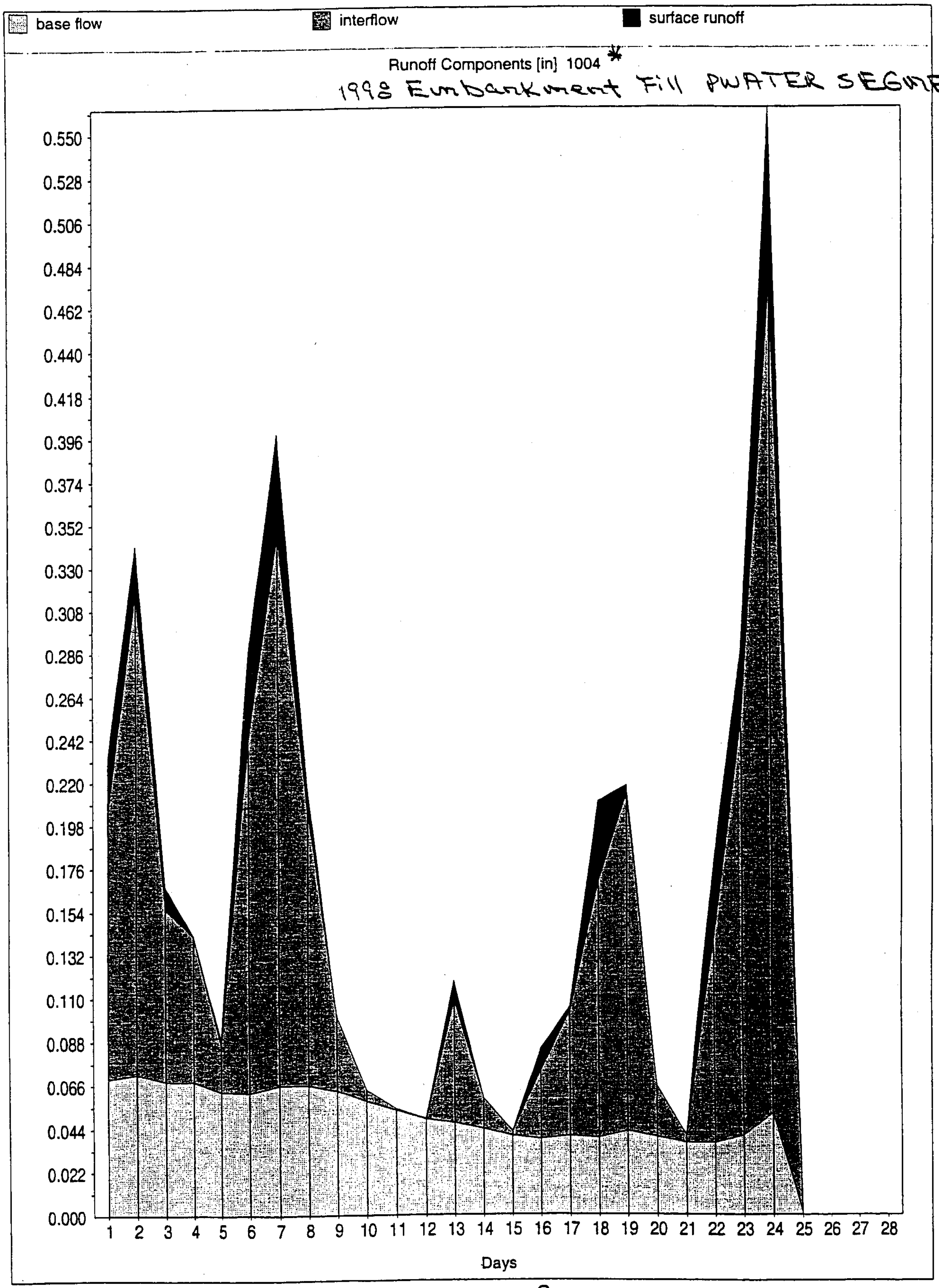
* 1998 Embankment Sedimentation Pond

TOTAL RUNOFF FOR PERIOD:
SIMULATED - 6.87 ac-ft
OBSERVED - 6.83 ac-ft
} +0.5 % Difference

SIMULATED

OBSERVED

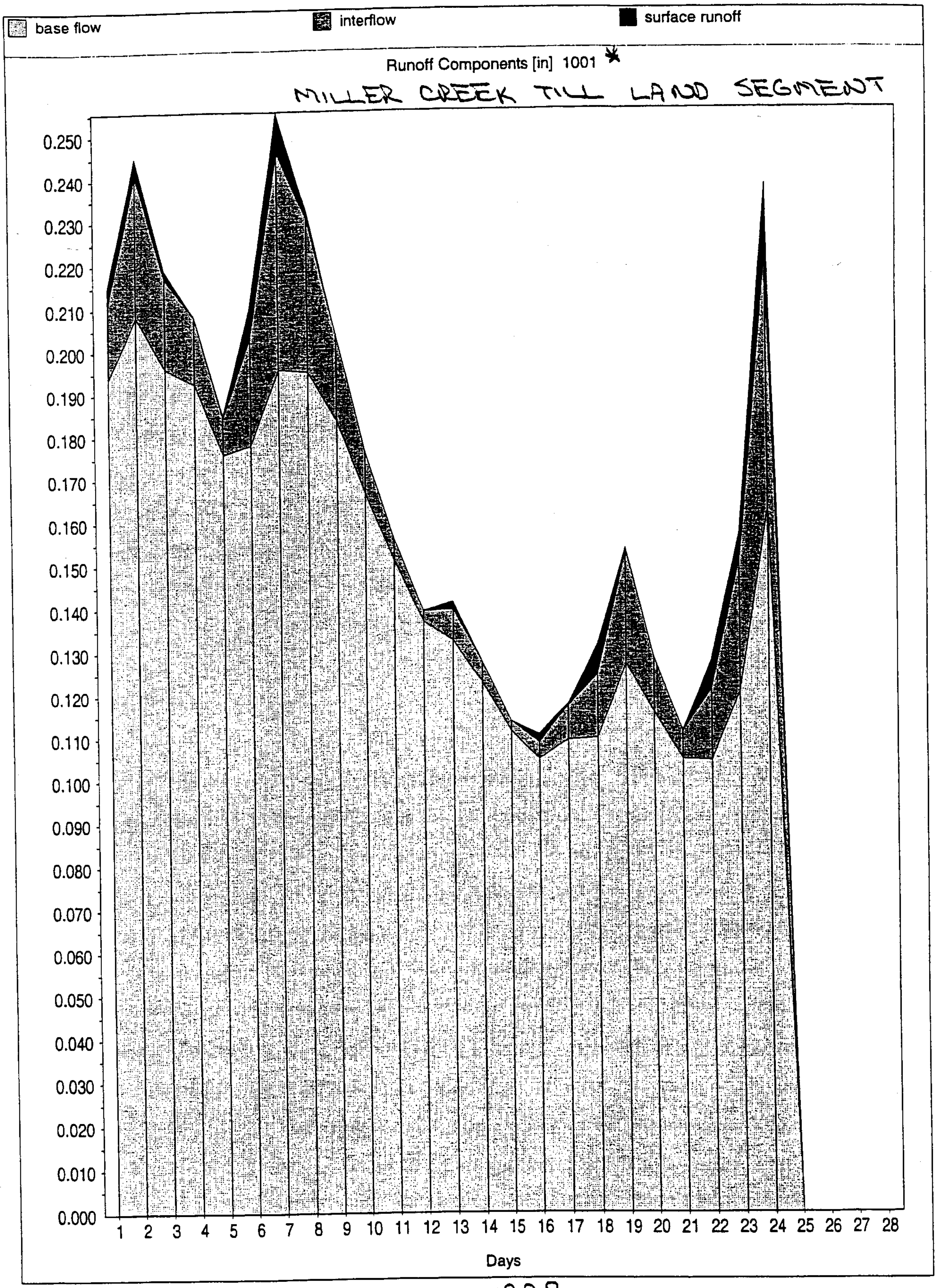
February 1999



1998 Embankment Fill PWATER SEGMENT

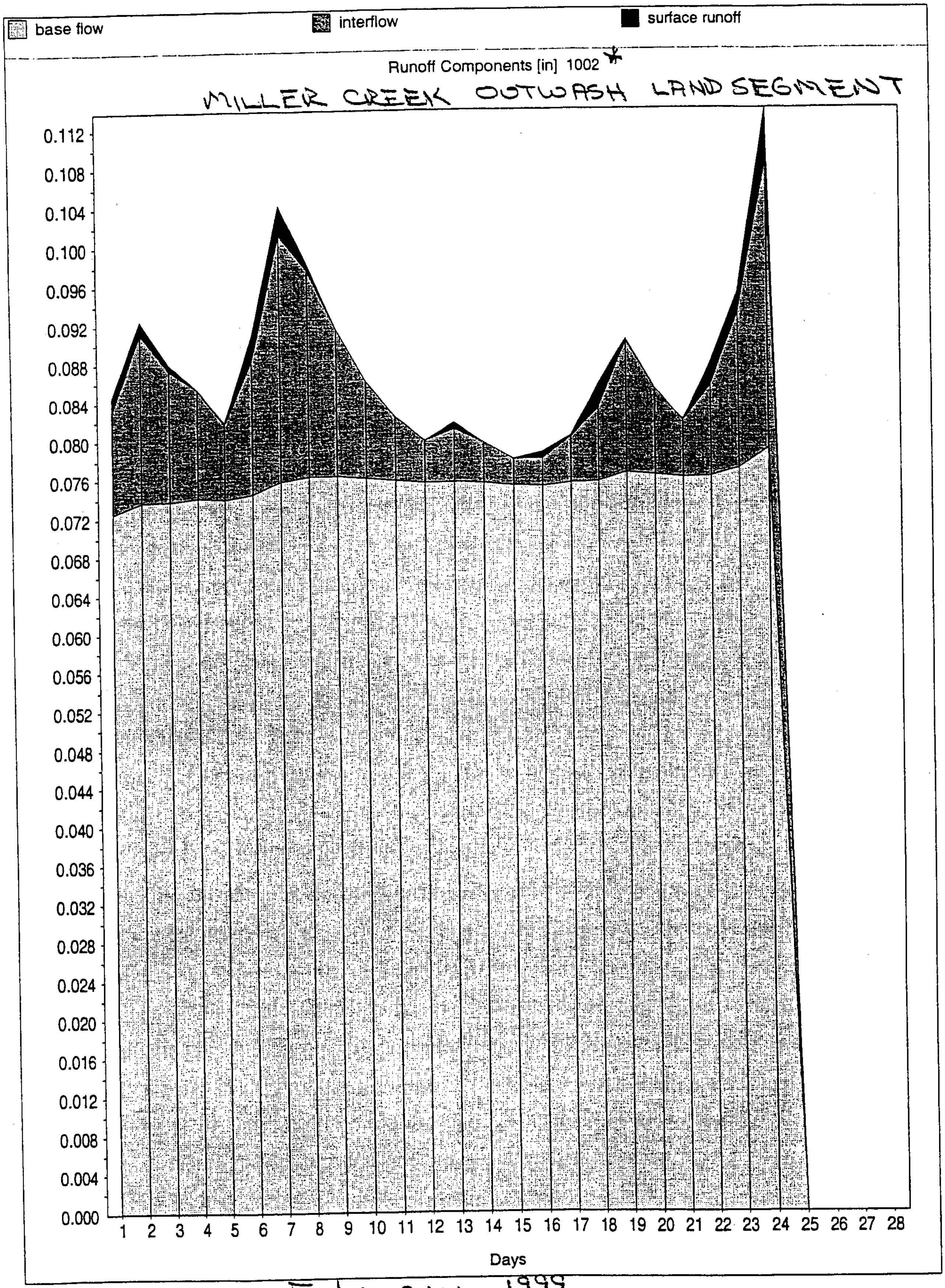
February 1999

PAGE 5



MILLER CREEK TILL LAND SEGMENT

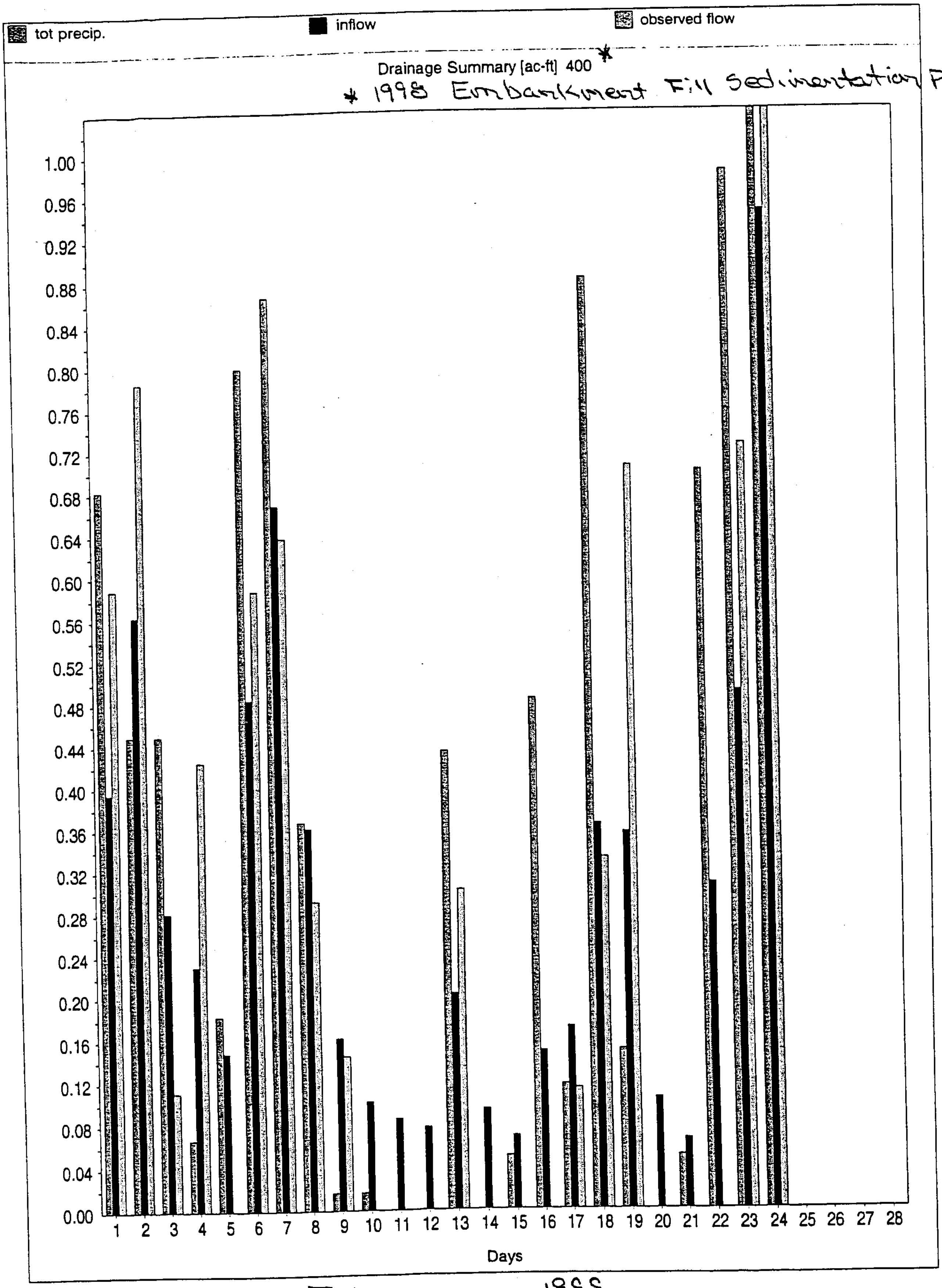
February 1999



MILLER CREEK OUTWASH LAND SEGMENT

February 1999

PAGE 7

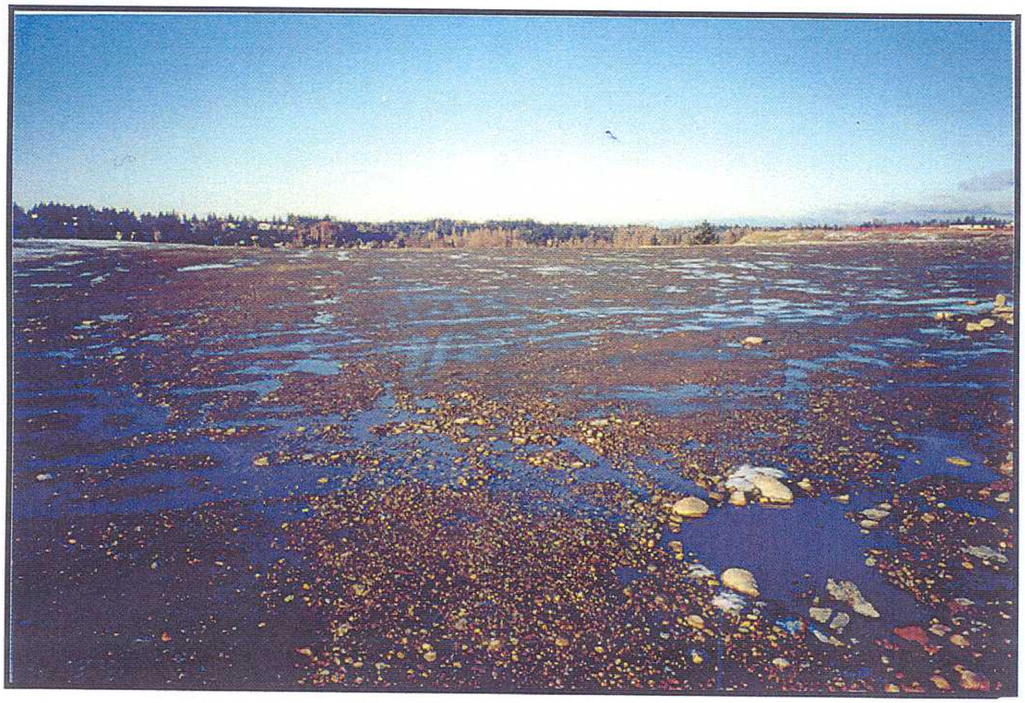


* 1998 Embankment Fill Sedimentation Pond

February 1999

PAGE 8

Exhibit I: Standing water on the top of the fill embankment at about South 160th Street, 28 January 2002



J

Exhibit J: Exposed face of fill embankment at site of slope failure near South 160th Street showing distinct layering and lack of homogeneity, 28 January 2002

Note: Exposed face in photograph is approximately 4 feet high by 3 feet wide.

www.bluebirdonline.com

K

Table 3-1
Summary of Water Volumes

	Water Available to Filer Strip	Water Available to OPA	Runoff from Filter Strip (RO1)	Runoff from Other Pervious Area (RO2)	Water excluded by Hydrus (RO3)	Water artificially removed from Hydrus to promote stability (RO4)	Total Runoff	Total Infiltration
Miller Creek Modeled Fill Area (ft3)	69,006,366	29,689,341	19,625,881	1,652,948	220,585	0	21,499,415	77,196,293
Miller Creek Modeled Fill Area (percent of total water)	70%	30%	20%	2%	0%	0%	22%	78%
Walker Creek Modeled Fill Area (ft3)	12,821,485	1,688,604	2,650,317	94,013	40,091	8,686	2,793,108	11,716,981
Walker Creek Modeled Fill Area (percent of total water)	88%	12%	18%	1%	0%	0%	19%	81%