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Efficiency of Sediment Basins

Analysis of the Sediment Basins Constructed as Part of the Straight Creek Erosion Control Project

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13. ABSTRACT (Maximum 200 words)

Erosion, sedimentation, and water pollution caused by runoff from the highway system are of concern to the Colorado Department of Transportation (CDOT). Compliance with federal and state water quality regulatory requirements along with a desire to minimize adverse environmental impacts have led to the need to control highway runoff. A variety of practices can be used to improve the quality of highway runoff and thereby reduce potential impacts to receiving waters. One such measure that can be constructed is a sediment basin.

The Straight Creek Erosion Control Project, completed by CDOT in the summer of 1994, included the construction of eleven sediment basins between the "toe" of the I-70 fill slope and Straight Creek. These basins were constructed to reduce highway runoff sediment loadings into Straight Creek.

This report provides information about the amount of material captured by the basins and their efficiency in removing sediment from the highway runoff. It is hoped that the report findings will help in future decisions on whether or not sediment basin construction is warranted and what sediment removal efficiency can be anticipated.

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Units of Measurement

Both English and metric (SI) units of measurement are used in this report; however, the English system is used primarily. This is mostly due to the facts that both the hydraulic design of the sediment basins and the survey of the sediment basins was performed in English units. The hydraulic design, completed in 1992, and the surveying, completed in 1993 and 1994, were done prior to the Colorado Department of Transportation's efforts to produce designs and surveys in SI units.

Units shown in the text of the report are provided in both English and SI units. English units are shown first, followed by a "soft" conversion to SI units.

Report figures and tables are in English units. In some of the tables, totals or final results, are displayed in both English and SI units.

The conventional unit of measurement for sediment sample analysis is SI units. Therefore, such items as sample concentration and sample mass are reported solely in SI units.

Executive Summary

Erosion, sedimentation, and water pollution caused by runoff from the highway system are of concern to the Colorado Department of Transportation (CDOT). Compliance with water quality regulations along with a desire to minimize adverse environmental impacts have led to the need for implementing and assessing practices to control highway runoff.

One practice that can be used to control pollutants in highway runoff is a sediment basin. Sediment basins are either constructed of embankment or excavated into the existing ground. They intercept and temporarily store a specific volume of stormwater runoff. To provide water quality enhancement, this runoff is very slowly released from the basin over an extended period of time. This results in conditions favorable for suspended sediment to settle out of the stormwater and be deposited on the basin floor. Consequently, water leaving the basin is "cleaner" than the water entering the basin.

As part of the Straight Creek Erosion Control Project, completed by CDOT in 1994, eleven sediment basins were constructed between the "toe" of the I-70 fill slope and Straight Creek. The basins were built to remove sand and sediment from highway runoff so that sediment loadings into Straight Creek would be reduced.

How much sand and sediment captured by these sediment basins along with the efficiency of the basins in removing sediment from the runoff are the primary subjects of this research report.
This report describes what data was collected and how it was collected. In addition, the data analysis and findings are presented.

A variety of surveying and monitoring efforts were completed to quantify the amount of material captured and efficiency of the basins. For example, surveying of the basins was completed to determine the volume of material captured. Flow measurement equipment was

installed and operated so that the water volume from the monitored runoff events could be determined. Water samples were collected and the concentration of sediment was determined for each of the samples. Also, sediment particle size for various soil and water samples was determined.

A number of conclusions were drawn as a result of this research. Most of the following conclusions that were reached are described based on the research objective that they support.

Research Object. 1:	Quantify the amount of sand captured by the sediment basins.
Conclusion:	Based on the surveying efforts and the relationship developed between drainage area and amount of sediment captured, it is estimated that 985 tons (894 m-ton) of sand and sediment are captured annually by the eleven sediment basins.
Research Object. 2:	Determine the efficiency of the basins in removing sediment from runoff.
Conclusion:	The efficiency of the sediment basins in removing sediment from runoff was based on monitoring sediment loading at the sediment basin at station 328+03 for a number of runoff events. The calculated TSS removal efficiency is 90.5%. In other words 90.5% of all sand and sediment that enters the basins will be captured.
Research Object. 3:	Determine the quantity of sediment released from the basins into Straight Creek.
Conclusion:	The quantity of sediment released from the basins into Straight Creek was determined based on the calculated removal efficiency and the annual quantity of sediment captured in the basins. On an annual basis a total of 1,088 tons (987 m-ton) will enter the basins. Of this amount, 985 tons (894 m-ton) will be intercepted and captured within the basins.

And 103 tons (93.4 m-ton) will be conveyed through the basins into Straight Creek. Therefore, sand and sediment loading into Straight Creek was reduced from 1,088 tons (987 m-ton) per year to 104 tons (93.4 m-ton) per year as a result of construction of the sediment basins.

Research Object. 4: Quantify the sediment loading differences between pavement and cut slope areas.

Conclusion: Based on the surveying efforts it was estimated that 101 pounds of sanding material per linear foot of highway (151 kg/m) for EB I-70 and 101 pounds of sanding material per linear foot of highway (151 kg/m) for WB I-70 would be captured annually by the sediment basins. In terms of pounds per acre of highway pavement, the estimated sand capture rate is 88,300 lb/acre (99,000 kg/ha).

In addition, it was estimated that 58,040 pounds per acre (65,100 kg/ha) of sediment from the cut slopes would be captured annually by the sediment basins.

Research Object. 5: Refine the estimate of the required maintenance clean out cycle.

Conclusion: The clean out cycles predicted during the design phase of the Straight Creek Erosion Control project, for most of the basins, were found to be reasonable when compared with the anticipated clean out cycle based on the survey information. Based on the surveyed information, the anticipated sediment removal cycle varies from once every 0.9 years at station 401+00 to once every 9.1 years at station 286+79.

Even with the refined estimate of the necessary basin clean out cycle, it is very important to keep in mind that CDOT Maintenance forces should routinely observe the basins to assess sediment removal needs.

Information provided in the October 1993 "Sediment Pond Maintenance Report" should help Maintenance forces more accurately identify when sediment removal is required. This is especially necessary considering the facts that some of the actual constructed volumes of the basins differ from the design volumes, that the sand application rates will vary from year to year depending on the weather conditions, and that maintenance practices may vary.

Other conclusions reached as a result of the research are:

- An analysis of the size of sediment in the runoff exiting the basin was completed. This showed that for all rainfall, simulation, and snowmelt events: no material larger than #60 (0.25 mm) sieve left the basin.

- The total cost to construct the basins and the anticipated cost to build the access road is $864,980. Assuming a 25-year life for the basins, the unit cost to capture the sanding and sediment material is $35/ton ($39/m-ton). Maintenance costs were not included.

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1.0 Introduction

Erosion, sedimentation, and water pollution caused by runoff from the highway system are of concern to the Colorado Department of Transportation (CDOT). Compliance with federal and state water quality regulatory requirements along with a desire to minimize adverse environmental impacts have led to the need to control highway runoff.

A variety of practices can be used to improve the quality of highway runoff and thereby reduce potential impacts to receiving waters. These include such things as planning and design of the highway location and configuration with water quality in mind, appropriate maintenance procedures, and construction of measures to remove pollutants. One such measure that can be constructed is a sediment basin.

Sediment basins are constructed of embankment or excavated into the existing ground. Sometimes a combination of excavation and embankment is used to build the basin. They intercept and temporarily store a specific volume of stormwater runoff. To provide water quality enhancement, this runoff is very slowly released from the basin over an extended period of time. This results in conditions favorable for suspended sediment to settle out of the stormwater and be deposited on the basin floor. Consequently water leaving the basin will be "cleaner" than the water entering the basin.

The Straight Creek Erosion Control Project, completed by CDOT in the summer of 1994, included implementation of a number of measures to reduce the water quality impacts to Straight Creek from highway runoff. One of the prominent measures implemented for the purpose of reducing sediment loadings into Straight Creek, was the construction of sediment basins. Eleven basins were constructed between the "toe" of the I-70 fill slope and Straight Creek.

Evaluation of the quantity of sediment collected by and removal efficiency of the sediment basins is the primary subject of this research report. To determine this, a number of steps had to be taken and parameters quantified. For example, surveying of the basins was completed to determine the volume of material captured. Flow measurement equipment was installed and operated so that the water volume from runoff events could be determined. Water samples were collected and the concentration of sediment was determined for each of the samples. Also, sediment particle size for various soil and water samples was determined.

This report describes what data was collected and how it was collected. In addition, the data analysis and study findings are presented. Finally, conclusions are provided.

2.0 Project Location and Background

The Straight Creek Erosion Control project was located along I-70, just west of the Eisenhower Tunnel. The project limits were from the west portal of the tunnel extending approximately six miles west toward the town of Silverthorne. All of the project construction, except for one sediment basin, was within 2.5 miles (9.7 km) of the tunnel.

Straight Creek is situated on the south side of I-70, and the highway parallels the creek. The Interstate was completed in early 1970. Since then, the creek has been impacted by above normal sediment loadings from the operation of the highway.

Sources of highway sediment and sand to Straight Creek are:

1) Sheet and rill erosion of the highway cut slope.
2) Sheet and rill erosion of the highway fill slope.
3) Gully erosion of the fill slope where culverts discharge onto the slope.
4) Sanding of the pavement necessary during the winter for vehicle traction purposes.

Of the above listed sources, two contribute sand and sediment into the sediment basins. These two sources of material are: (1) sheet and rill erosion from the cut slope and (2) sanding of the pavement necessary for vehicle traction purposes. Culvert gully erosion at the sediment basin locations was repaired by the Straight Creek project; therefore, sediment is not delivered into the basins from this source. Only a very small fill slope area is tributary to the sediment basins; therefore, the sediment quantity delivered to the basins from this source is negligible.

The cut and fill slopes within the project corridor are very steep with slopes ranging from 1:1 (H:V) to 1.5:1. The steep slopes, lack of vegetative cover, and runoff on the slopes have caused material to be eroded. Some of this eroded material is transported via runoff into Straight Creek.

In addition, much sand is applied to the highway due to the very difficult climatic and terrain conditions of the project area. On average, 40 inches (102 cm) of precipitation fall annually. Most of this is in the form of snow. The elevation within the project area is 10,500 feet (3,200 m) and the longitudinal grade of I-70 is steep at 6%. The sand applied by CDOT Maintenance forces provides the traction necessary to keep I-70 traffic moving in as safe and efficient manner as possible. Some of this sand is transported via highway runoff to Straight Creek.

Figure 2.1 is a photo showing sanding material on Westbound (WB) I-70 and also some cut slope areas. Figure 2.2 is a photo of Eastbound (EB) I-70 with sanding material being transported during a snowmelt runoff event.

To reduce the sediment loading into Straight Creek, CDOT implemented the Straight Creek Erosion Control project. As part of the project, other erosion control practices were implemented in addition to the construction of the eleven sediment basins. For example, approximately 50 acres (20 ha) of the I-70 fill slope were seeded and mulched. This was done to establish additional vegetation so that the fill slope would be less susceptible to erosion. Subsequently, less sediment would be eroded from the slopes and transported to Straight Creek.

Figure 2.1 - Looking west at WB I-70 and cut slope areas. Note traction sand on roadway and mixed with plowed snow. Photo taken Fall 1995.

Figure 2.2 - Looking west at EB I-70. Note the large amount of sanding material and snowmelt transporting some of this sand. Photo taken Spring 1993.

Another practice implemented was construction of pipe rundowns on the fill slope. These rundowns were installed in a number of locations to prevent additional gully erosion of the fill slope.

Figure 2.3 is a schematic showing the approximate location of the sediment basins. Also shown is the location of I-70, Straight Creek, the highway cut slopes, and the highway fill slopes. It should be noted that the figure is not to scale. Also, there are numerous inlet/pipe systems and culverts that exist that are not shown. Only those drainage features that carry runoff into the basins are displayed.

Figures 2.4 and 2.5 illustrate one of the basins (station 369+67) during construction and the same basin in operation.

3.0 Objectives

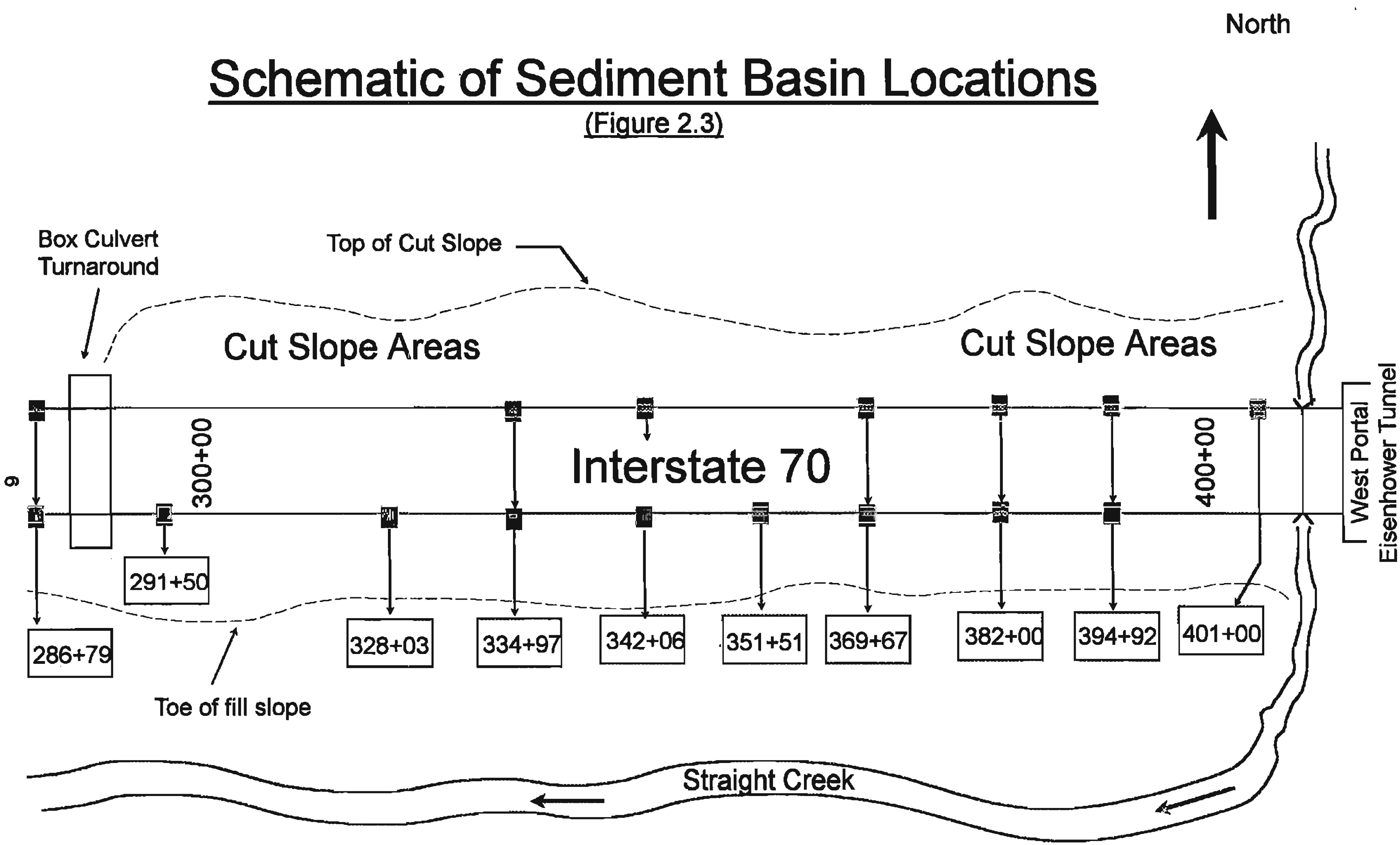
In the future CDOT will certainly consider implementing sediment basins similar to the ones used on the Straight Creek project. One reason for this is more awareness of the potential adverse impacts to receiving water from sediments. Also, requirements such as the National Pollutant Discharge Elimination System (NPDES) stormwater regulation requires that stormwater quality be addressed. Finally, more emphasis is being given by regulatory agencies such as the Environmental Protection Agency and the Colorado Department of Public Health and Environment to controlling non-point source pollution.

As a result, it is necessary to evaluate the sediment removal effectiveness of the constructed sediment basins. The primary objectives of this research were to determine the:

1) quantity of sand captured by the sediment basins.

Schematic of Sediment Basin Locations

(Figure 2.3)



Legend

- Sediment Basins
- Drop Inlet and Pipe

- No Scale. Locations Approximate.
- A number of existing inlet/pipe systems and culverts between the Box Culvert Turnaround and the Tunnel that are not shown. Only those that carry runoff into the basins are displayed.
- Sediment basin at 127+00 not shown.

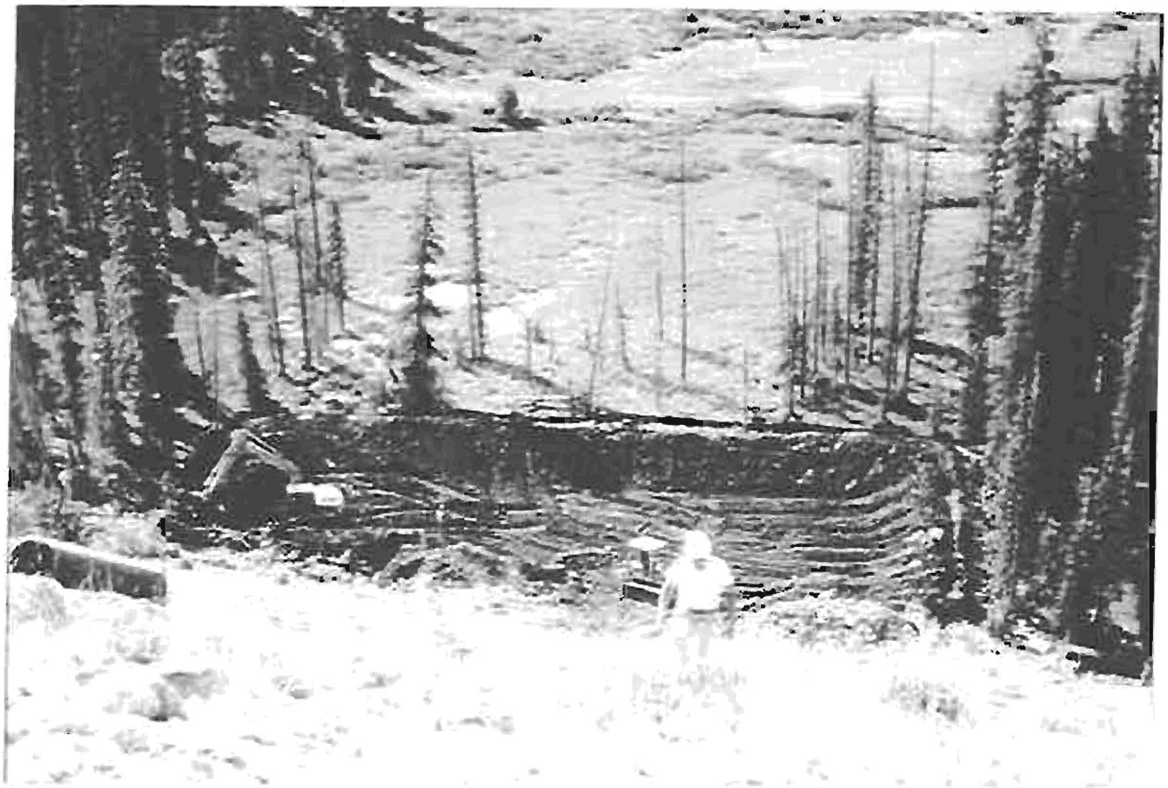


Figure 2.4 - Sediment Basin at 369+67 during construction. Photo taken Summer 1993.

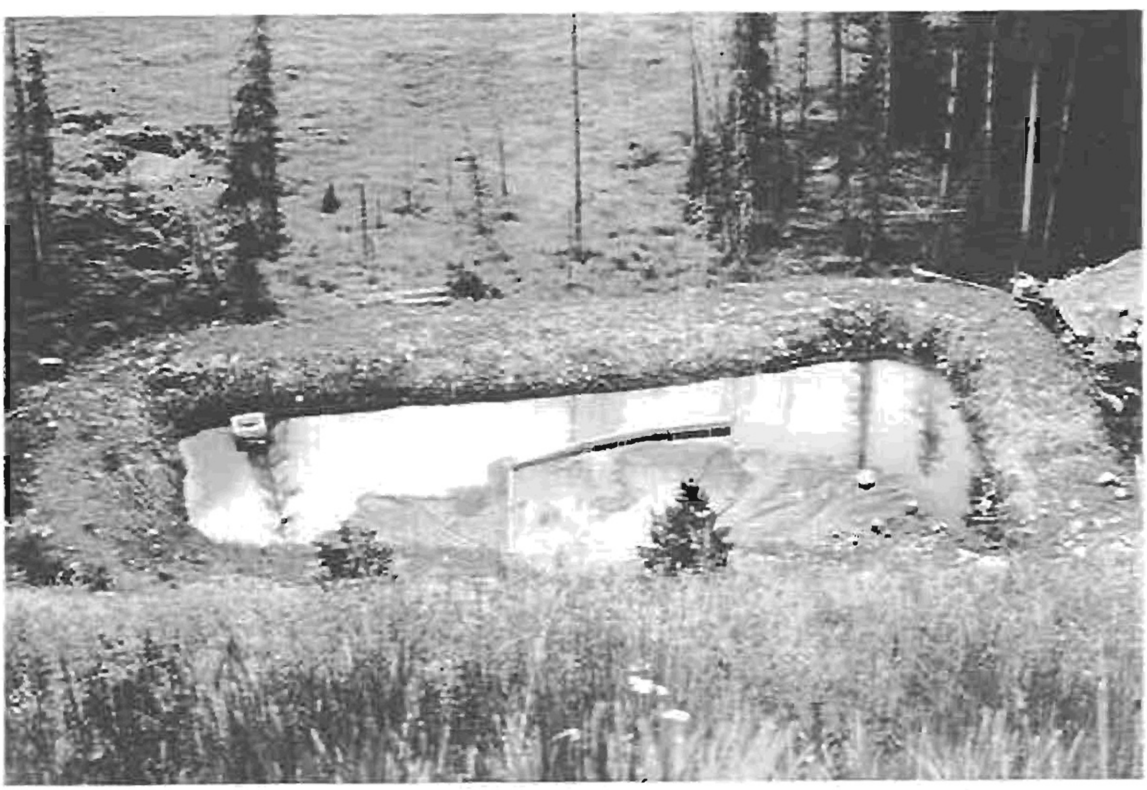


Figure 2.5 - Sediment Basin at 369+67 in operation. Photo taken Summer 1995.

2) efficiency of the basins in removing sediment from the runoff.
3) quantity of sediment released from the basins into Straight Creek.
4) sediment loading differences between pavement and cut slope areas.
5) necessary refinement to required maintenance clean out cycle.

This report provides information about the amount of material captured by the basins and their efficiency in removing sediment from the highway runoff. It is hoped that the report findings will aid in future decisions on whether or not sediment basin construction is warranted and what sediment removal efficiency can be anticipated.

4.0 EXISTING INFORMATION

Information presented in this section describes the hydraulic design of the sediment basins and the monitoring planning documents that were prepared. Specifically the following three items will be discussed:

- CDOT hydraulic design of the Straight Creek sediment basins.
- USGS report - "Monitoring of CDOT Straight Creek Sediment Ponds."
- CDOT report - Straight Creek Erosion Control Project - "Study Design for Sediment Pond Monitoring."

4.1 Hydraulic Design

The hydraulic design of the sediment basins was completed by the CDOT Hydraulics Unit in 1992. The primary design focus was twofold. First, the required basin volume for storage of runoff and sediment had to be determined. Second, an appropriate release structure for metering the runoff slowly out of the basin had to be designed.

Design Volume of the Sediment Basins

The sediment basins were sized for two components: a water quality capture volume (WQCV) and an expected sediment loading volume. The summation of these two volumes determined the necessary basin volume.

Computation of the WQCV was based on each basin capturing runoff from 0.5 inches of precipitation from the tributary drainage area. The WQCV was computed using the following equation:

$$WQCV = \frac{DA \times c \times 0.5 \times 43{,}560}{12}$$

where: WQCV = required basin volume for stormwater improvement (ft^3)

DA = drainage area (acre)

c = runoff coefficient

Capturing this volume ensures that runoff from the vast majority of precipitation events will be captured by the basins. An analysis was completed for a previous adjacent CDOT project in 1974 of the precipitation gage near Dillon CO (approximately 7 miles (11 km) west of the project site). For rainfall events occurring from May through September, that exceed 0.1 inch (0.25 cm), on average only two out of 23 events exceeded 0.5 inch (1.2 cm). In addition, for all precipitation events (including snow) more than 0.1 inch (0.25 cm), on average only two out of 50 events exceeded 0.5 inch (1.2 cm). This analysis of the precipitation gage points out that runoff from the vast majority of precipitation events will be entirely captured by the sediment basins. It should be mentioned that because the project site is at a higher elevation than Dillon, the frequency and amount of precipitation at the site are more than that indicated by the precipitation gage.

Finally, it should be pointed out that between maintenance sediment clean out cycles there will be excess basin volume for storage of runoff. This sediment storage volume will actually be available for runoff volume accommodation until the sediment storage volume has been filled. If the sediment removal maintenance frequency is implemented as recommended in the "Sediment Pond Maintenance Report" there will be extra volume for storage of runoff.

As was described earlier in Section 2.0, the sources of sediment loading into the basins comprise two components. One component is erosion of material from the I-70 cut slope and the other is sand from winter sanding operations. The expected annual sediment loading volume into each basin was estimated using highway sanding application rates provided by CDOT Maintenance, by estimating the amount of erosion from the cut slopes, and by predicting how much of the sand and cut slope sediment would be transported by runoff into the basins.

The basins were sized to have an adequate sediment storage volume to either capture two years or five years of sediment loading. In some basin locations, the area available for pond construction was constrained by the steep terrain, encroachment into wetlands, or right-of-way limits. For these locations the basins were sized for capturing two years of sediment. In other locations the basins were sized for capturing five years of sediment.

The geometry of each basin was designed similarly. The maximum depth in each basin for the WQCV and sediment storage was limited to 4 feet (1.2 m). In addition, each basin was designed based on a rectangular shape. The longest basin side was set to the nearest 10 feet (3 m) that would provide adequate storage volume for both the runoff and sediment. The length of the other side was set at one half the length of the longest side. See Figure 4.1.

The longest side of the rectangular basin was set to be parallel with the toe of the I-70 fill slope. Ideally, it would have been preferred to have the longest basin dimension oriented perpendicular to the fill slope. This would have increased the travel distance of the runoff entering the basin to the release structure. As a result, this may have enhanced sediment removal efficiency and minimized potential "short circuiting." However, because of the very

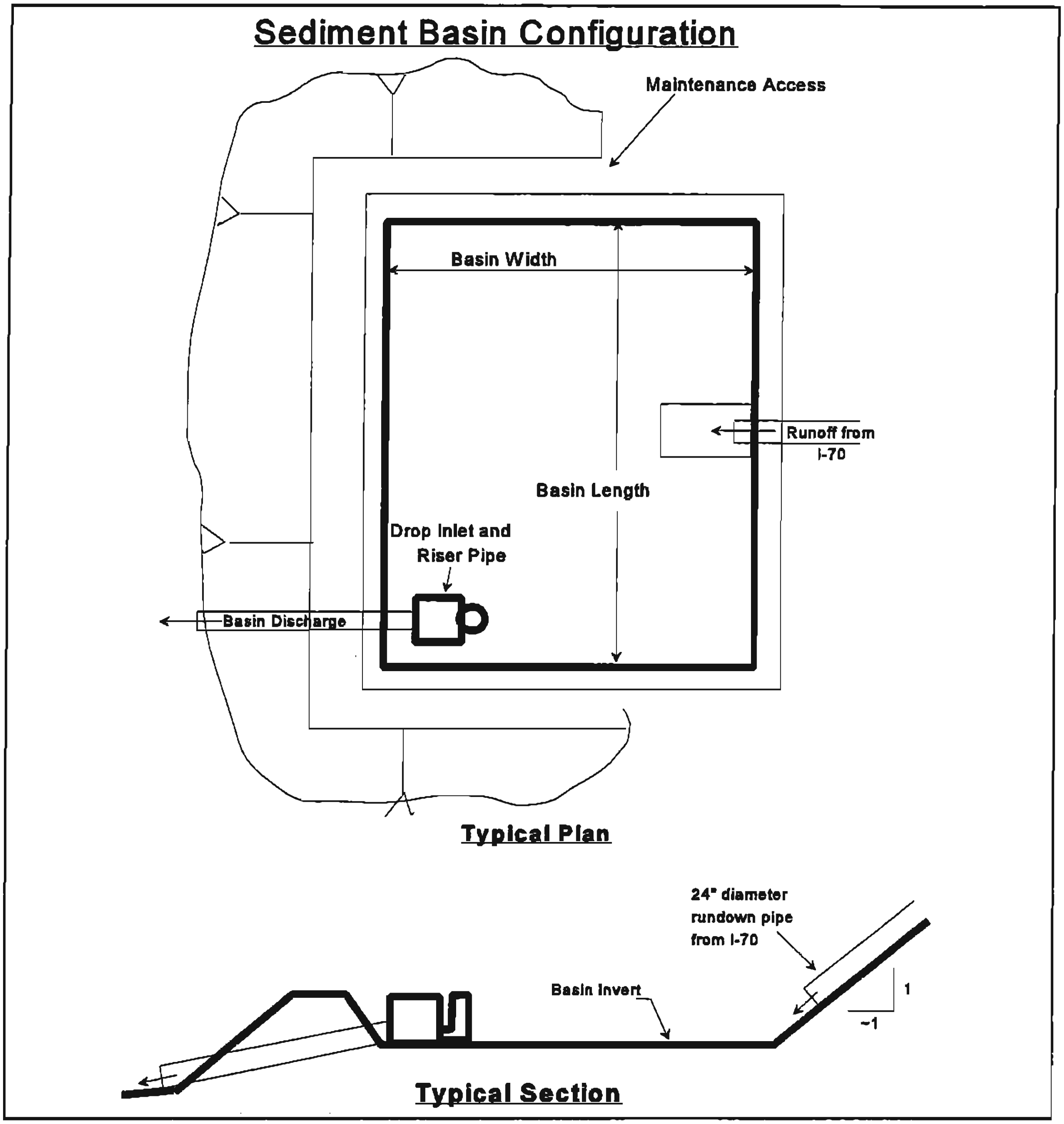


Figure 4.1: Sediment Basin Configuration

steep terrain it was necessary to construct the long side of the basin parallel to the fill slope so that the basin embankment would not be excessively long since the embankment slope would not have "caught" the terrain slope for some distance.

It should be pointed out that the actual constructed basin geometry varied somewhat from the design geometry. The contractor was given some flexibility as to the actual shape, size and depth of the constructed basins.

Design of the Basin Release Structure

The release structure, installed in each of the sediment basins, consisted of a drop inlet and a 12 inch diameter perforated riser pipe attached to the drop inlet. See Figure 4.2.

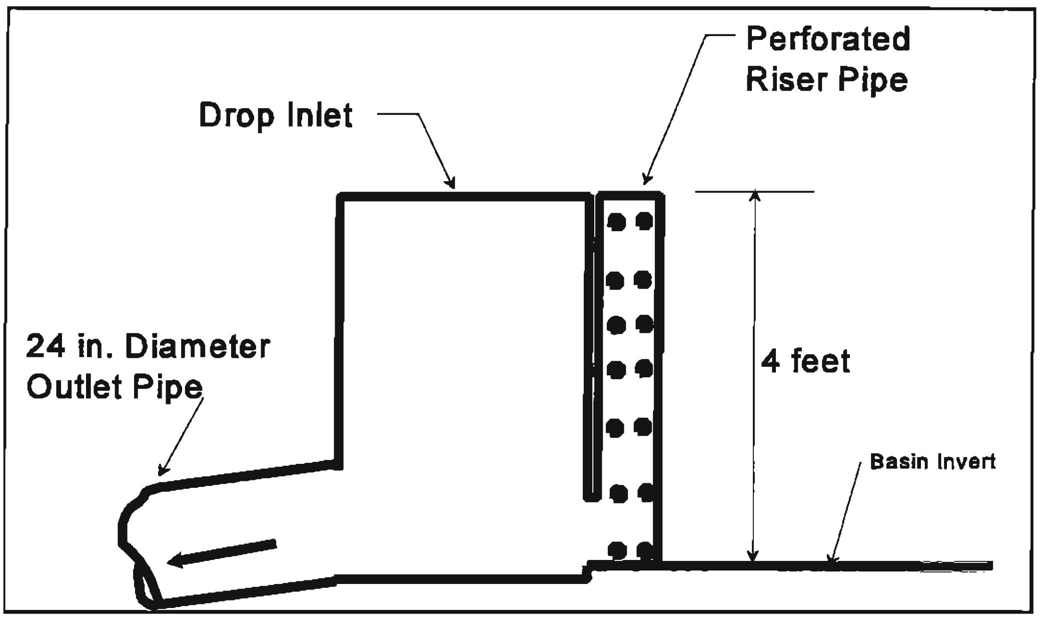


Figure 4.2: Release Structure

The perforated riser pipe is used to control the rate at which runoff exits the basin. The perforation size and locations were determined so that runoff was metered very slowly out of the basin. The perforation size is 0.5 inch (1.27 cm) diameter. The perforation vertical spacing is basically on 6 inch (15 cm) centers and there are five to six perforations in each row.

The Urban Drainage and Flood Control District in their Volume 3 Drainage Criteria Manual recommend a 12-hour release period for sediment basins when used to remove sediment from runoff from construction activities. Considering that the need of the basins was to remove sediment, most of which is sand size, it was decided that a release time for the WQCV of approximately 12 hours should provide adequate sediment removal efficiency.

It should be noted that the perforation size and spacing of all eleven basin riser pipes were designed to be the same so as to provide consistency for construction purposes. The perforation design for each sediment basin riser pipe was not modified to try and achieve precisely a 12-hour release period for the WQCV. The 12-hour emptying time was a target value. Some of the basins will release the WQCV volume in less than 12 hours. Others will release the WQCV in more than 12 hours.

For situations where it is desired to remove smaller particles and other pollutants that are typical of highways where sediment is not the main concern, a 12-hour release time would be too fast and therefore a slower release time should be used. Guidance is given in CDOT's Erosion Control and Stormwater Quality Guide.

4.2 USGS Report

CDOT requested that United States Geologic Survey (USGS) provide their expertise for identifying options for monitoring of the sediment basins. Randy Parker from the USGS assessed and identified these monitoring options. The April 1994 report, "Monitoring of CDOT Straight Creek Sediment Ponds," along with discussions and insight provided by Randy, helped greatly to identify the monitoring considerations and constraints.

4.3 Study Design for Sediment Basin Monitoring

This draft "Study Design for Sediment Pond Monitoring" report was completed in May 1994. The purpose of the report was to describe monitoring efforts that would be undertaken to quantify the effectiveness of the basins. Specifically, it was developed to define a monitoring plan that would be used for acquiring data to accomplish the research objectives.

The research objectives identified in the draft study design report are basically the same as those discussed in Section 3.0 above. Also, the specific steps required to accomplish each of the objectives was identified. In addition, the needed automatic sampling and flow measurement equipment was identified. Finally, a schedule for completing the monitoring activities was included.

5.0 Monitoring Efforts

A variety of monitoring efforts were implemented to determine the quantity of sediment captured and to determine the efficiency of the sediment basins. These efforts included: surveying of the basins; installation of primary flow measurement devices, flow recording equipment, and automatic samplers; determination of the sediment concentration of collected samples; and sediment size analysis for soil and water samples.

Surveying of the sediment basins was completed to determine the volume of sediment captured in the basins over a period of time. A survey in the fall of 1993 was completed to establish the baseline information about the geometry of the basins. One year later, in the fall of 1994, the same basins were resurveyed.

Most of the monitoring efforts besides surveying were undertaken to provide data to determine the efficiency of the basins in removing sediment from runoff. The desire was to acquire enough information through monitoring of runoff and sediment loading to be able to use the principles of the Mass Balance equation to solve for unknowns about the sediment loading and runoff volumes. The three mass balance terms evaluated by the monitoring efforts are: basin inflow, basin outflow, and change in storage. Through monitoring, two of the three mass balance terms can be quantified. The third term can then be found using the Mass Balance equation.

Mass Balance Equation:

$$O = I \pm \delta S$$

where: O = outflow from sediment basin (water or sediment)

I = inflow into sediment basin (water or sediment)

δS = change in storage in the sediment basin (water or sediment)

If needed, additional terms could be inserted into the equation for such parameters as infiltration into the basin floor or errors that may result from measurement.

After quantifying the sediment inflow, outflow, and change in storage for a runoff event or a series of runoff events, the efficiency of the basin can be determined. The removal efficiency of the basin is the percent of sediment entering the basin that is captured.

Removal Efficiency Equation:

$$Eff.(\%) = \frac{I - O}{I} \times 100$$

where: eff. = percent of sediment removed by the basin

I = defined above

O = defined above

5.1 Monitoring Equipment

Personnel were not available to "chase" storms and be consistently available at the site during runoff events to collect samples and measure flow rates. Due to the temporal and spatial variability of precipitation events it is not always possible to schedule manpower resources to routinely collect samples and measure flow. In addition, motorized access to the basins was not available. To reach the basins to be monitored, the 250 feet (76 m) long, 1:1, rocky fill slope had to be descended and climbed. A laptop computer along with other materials had to be hand carried over the fill. Traversing the fill slope while carrying these materials during storm events or at night would have been difficult and dangerous. Therefore, due to variability of precipitation events and poor site access - installation of automatic monitoring equipment was necessary.

Automatic monitoring equipment needed to complete the research included: primary flow measurement devices, automatic samplers, pressure transducers, data loggers, and other equipment. A summary list of the equipment used is shown in Table 5.1.

Table 5.1
List of Monitoring Equipment Used

Sampling Equipment	**Flow Measurement Equipment**
2 - ISCO automatic samplers	3" Parshall flume
1- SIGMA automatic sampler	6" Parshall flume
	90° v-notch weir.
Depth Sensor and Data Loggers	**Other Equipment**
1 - Keller submersible Pressure Transducer	3 - Housing units for monitoring equipment
2 - ISCO submersible pressure transducers	deep cycle marine batteries
1 - Campbell Scientific datalogger	laptop computer
2 - ISCO dataloggers	sample bottles

A primary flow measurement device, when inserted into runoff, creates a geometric relationship between the depth of flow, or head, and the flow rate. The head is measured at a specific location, depending upon on the type of measuring device. The head value can be substituted into a hydraulic equation to determine the flow rate. Primary flow measurement devices used for the monitoring included two parshall flumes, a 3 inch (7.6 cm) and a 6 inch (15.2 cm) wide flume, along with a 90° v-notch weir.

Portable automatic samplers were used to collect runoff samples. The samplers were powered by deep cycle marine batteries. Each sampler held 24, 1000 ml, polypropylene sample bottles.

The automatic sampling equipment was preprogramed to collect samples for the entire duration of a runoff event. The sampling equipment was automatically activated when the runoff event began and automatically deactivated once the runoff was complete. Typically, at the beginning of the event, samples were collected on a five to 15 minute interval. After this, samples were collected once every hour.

A peristaltic pump, contained within the sampler, pumped water from the sample intake point into the sample bottles. Each sampling cycle included an air pre-sample purge and post-sample purge to clear the suction line before and after sampling.

Submersible pressure transducers were used to measure the water level in feet. Level readings were taken continuously, during dry periods and during runoff events. Obtained water level readings were converted to flow rate values using the appropriate hydraulic equation (described below).

Data loggers were used to continuously record and store level data. Every five minutes the pressure transducer level values along with the time of the reading was stored in the datalogger memory. The dataloggers were powered by two six volt alkaline lantern batteries.

A laptop computer was used to extract the level reading data from the data logger.

To prevent theft and vandalism, the monitoring equipment was kept in a housing unit. The housing unit was locked and it was secured in place by anchors or cables. The housing unit was made of metal and it was approximately 3 feet (1 m) by 3 feet (1 m) at the base and 2.5 feet (0.8 m) tall.

5.2 Monitoring Location and Scheme

To determine sediment removal efficiency, monitoring of runoff events was undertaken at two different sediment basins. One of the basins monitored was at station 328+03. The other basin was at station 342+06.

The monitoring data obtained at 342+06 was not analyzed nor used in this research report since the data obtained was not reliable. During the monitoring period there were numerous times when the data logger readings were not reasonable. This problem could have been due to a poor wiring connection between the battery power source and the datalogger. Or it could have been due to the datalogger malfunctioning. As a result of the unreliable datalogger values, it is not possible to accurately determine the hydrograph (flow rate and time relationship) values for runoff events. In addition, due to the datalogger problems, only a limited number of runoff samples were collected. Therefore, accurate determination of the sediment concentration for storm events was not possible.

Fortunately, monitoring runoff and collecting runoff samples presented far fewer problems at the sediment basin at station 328+03. Therefore, the results of the monitoring at 328+03 will be used to determine the sediment removal efficiency of the sediment basins.

At station 328+03, the hydrograph values were obtained for stormwater runoff events. The volume of runoff entering the basin and exiting the basin was recorded by the dataloggers.

Runoff samples were collected for both basin inflow and outflow. Also, the sediment concentration in mg/l was determined for each of the samples.

To obtain the mass of sediment entering and leaving the basin for a runoff event, the sediment concentration values were multiplied by the appropriate runoff volume. The Mass Balance equation was then used to determine how much sediment was captured within the basin. Finally, having quantified the sediment inflow, outflow and amount captured - the sediment removal efficiency was then determined.

A 3 inch (7.6 cm) Parshall flume was installed just downstream of the basin discharge pipe. All water discharged from the basin was directed through the flume. Head in the flume was continuously measured by a pressure transducer. A datalogger recorded the head readings during periods of no flow and during runoff events. Installation of the flume along with continuously recording of the head in the flume provided the data necessary to determine the volume of runoff exiting the basin.

A 90-degree v-notch weir was installed in a drop inlet up-gradient of the sediment basin to facilitate measurement of the inflow volume. The weir head was continuously measured by a pressure transducer. A datalogger recorded the head readings during periods of no flow and during runoff events. Installation of the weir along with continuously recording of the head provided the data necessary to determine the volume of runoff entering the basin.

Flow depth information, saved in both the inflow and outflow dataloggers, were routinely retrieved. A laptop computer transferred information from the datalogger to an electronic computer file. These files were then later used to generate basin outflow hydrograph information.

Automatic samplers were also installed at the inflow and outflow points of the basin. The samplers collected water samples during the runoff events. Each of the collected samples was analyzed for sediment concentration. Figure 5.1 illustrates the monitoring scheme implemented at the sediment basin at station 328+03.

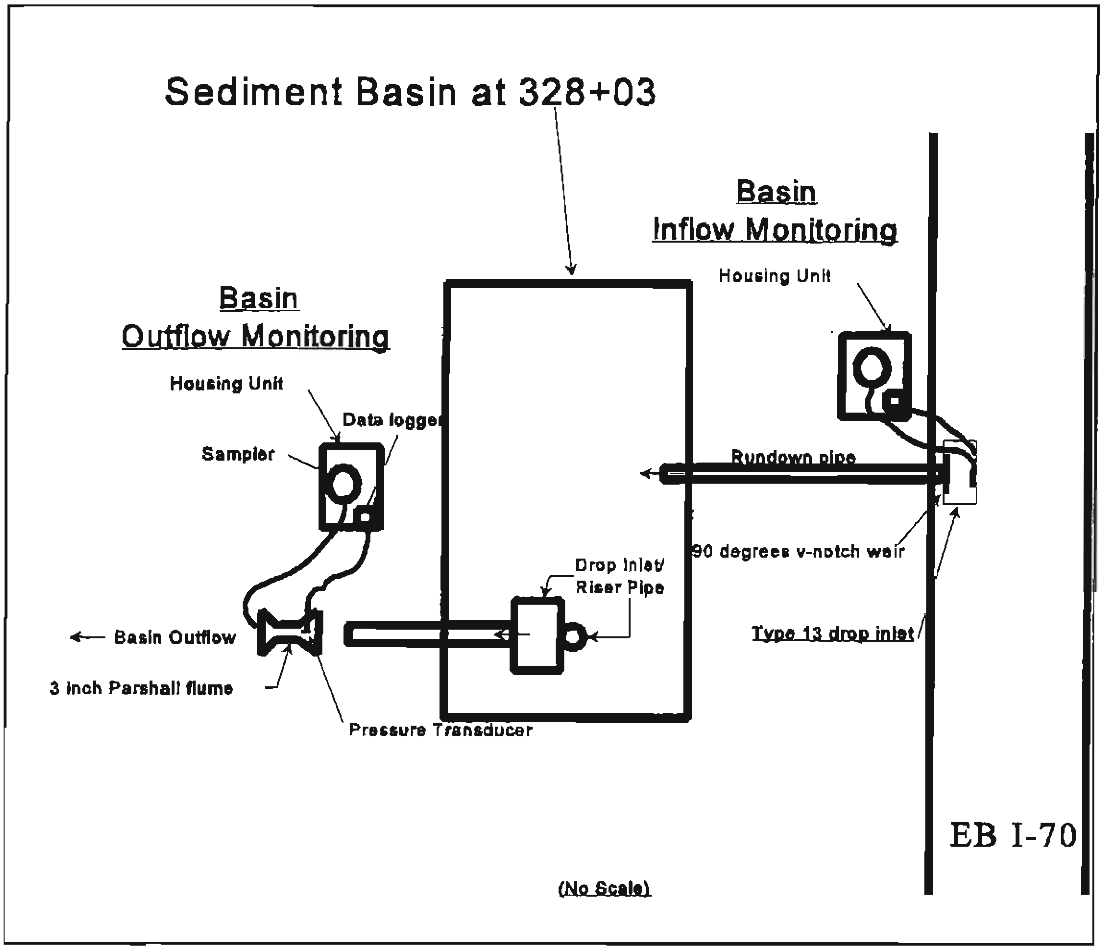


Figure 5.1: Monitoring Scheme

Figure 5.2 is a photo taken of the sampling equipment housing unit at the outlet of the sediment basin. Figure 5.3 is a photo that displays some of the sampling equipment that was used.

Figure 5.2 - Sampling Equipment at Basin Outlet. Note the sampler tube and pressure transducer line between the housing unit and the flume (lower right corner). Photo taken Summer, 1994.

Figure 5.3 - Sampling Equipment. From left to right: pressure transducer, automatic sampler, and flow data logger.

6.0 Data Collection and Analysis

The following sections describe the data collected and analyzed as part of this research which includes: basin surveying, runoff volume and sediment concentration, and sediment size of soil and water samples.

6.1 Basin Survey and Sediment Accumulation

Not all eleven basins were surveyed because at the time of the first surveying effort, which was the Fall of 1993, construction of all the basins had not been completed. To determine the volume of sediment captured, surveying was completed for the seven sediment basins that had been constructed.

The 1993 survey established the constructed geometry for each of the basins. Permanent bench marks were installed around the basin perimeter so that future surveying could be completed using the same elevation datum and cross section locations.

A baseline was established between two of the bench marks. These benchmarks were located on opposite ends of the basin and were installed on the top of the basin embankment. An elevation of 100 (30 m) was assumed for one of the benchmarks. Elevations of the survey shots were then determined relative to the assumed elevation.

Cross sections were surveyed throughout the basin interior and at the top of the basin embankment. The number of cross sections obtained for each basin varied depending upon the size of the basin. On average, 8 sections were obtained per basin.

In the Fall of 1994 each of the seven sediment basins was re-surveyed. Baselines were reestablished between the two benchmarks. Cross sections were re-surveyed at the same locations as they had been in 1993.

The survey data collected in 1993 and 1994 was entered into the software program Eaglepoint. This was done so that basin geometry and volume of sediment captured could be determined. In addition, Eaglepoint and Autocad were used to graphically display the cross sections and review the survey information. Figure 6.1 is an example of cross sections for one of the basins (station 369+67). Cross section plots, similar to Figure 6.1, were generated for each sediment basin.

Table 6.1 displays the survey dates and the volume of sediment captured for the seven basins. In all, the sediment basins captured 435 cy^3 (333 m^3) more than a one year period. The actual number of days between surveys is a little different from 365 days; however, for practical purposes it can be assumed that the captured volume represents the quantity for one calendar year. Most of the sediment transport occurs in the spring and early summer during snowmelt runoff events. Conversely relatively little sediment is transported during the Fall months of October and November. Therefore, not surveying exactly 365 days after the first survey in the Fall of the year will not provide significant error.

Table 6.1
Sediment Volume Captured by the Surveyed Basins

Sediment Basin Location	Date of 1st Survey	Date of 2nd Survey	Volume of Captured Sediment - yd^3
127+00	Oct 29, 1993	Oct 26, 1994	11
286+79	Nov 6, 1993	Oct 26, 1994	14
291+50	Oct 29, 1993	Oct 19, 1994	11
328+03	Nov 3, 1993	Oct 20, 1994	26
334+97	Nov 3, 1993	Oct 20, 1994	71
369+67	Oct 28, 1993	Oct 26, 1994	89
394+92	Oct 28, 1993	Oct 14, 1994	213
Total Volume Captured .... 435 yd^3 (333 m^3)			

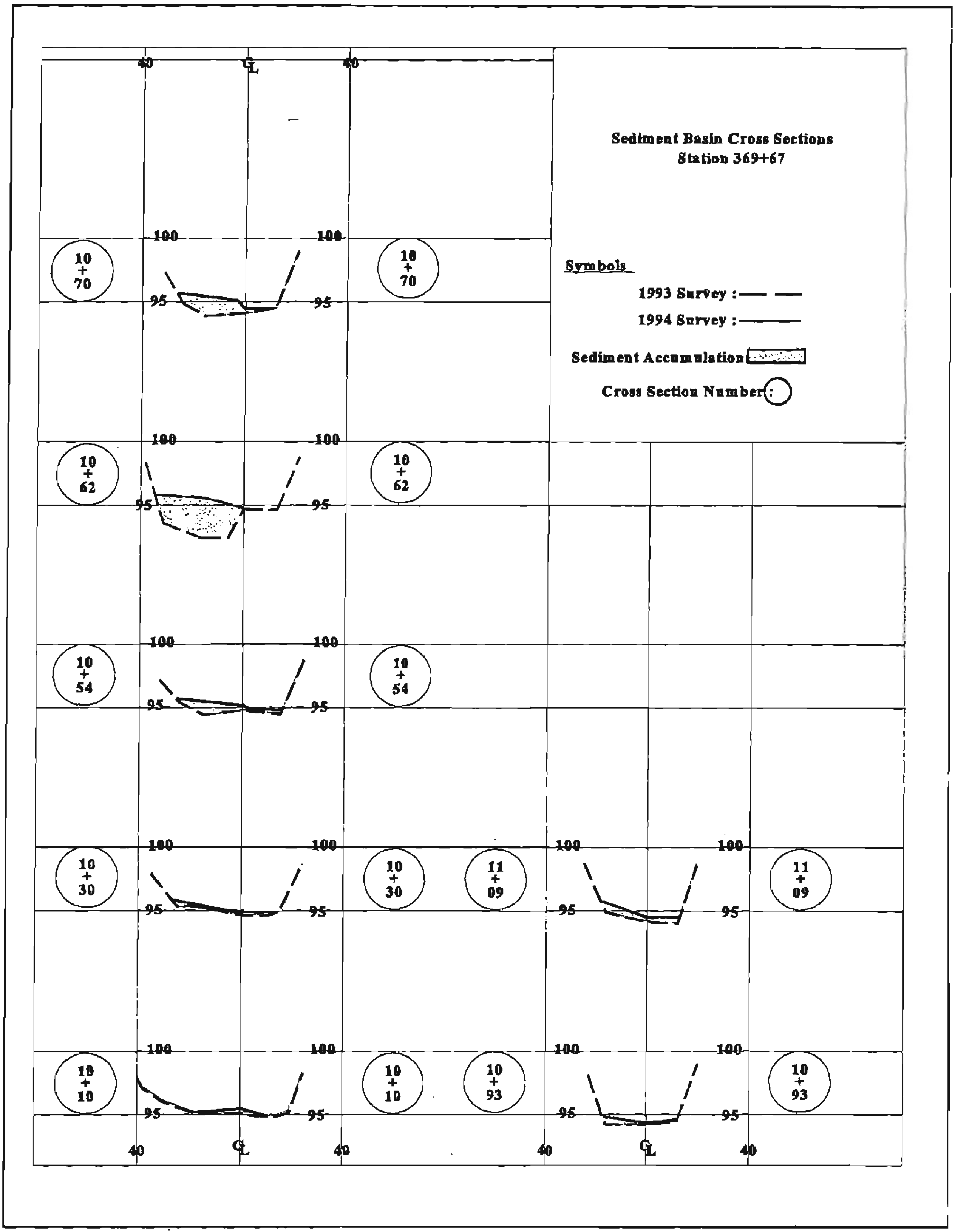


Figure 6.1: Sediment Basin Cross Sections

6.1.1 Weight of Sediment Captured

To determine the weight of sediment captured between the date of the first and second surveys, the volumes obtained from the surveying were multiplied by the unit weight (lb/ft^3) of in-situ sediment.

For unit weight determination two different methods were used. For the first method, samples of captured sediment were collected using a 2.84 inch (7.2 cm) diameter cylinder. Two samples were obtained from the sediment deposition in the basin at station 394+92 and a third sample was obtained from the basin at station 342+06.

The cylinder was slowly and carefully pushed into the sediment to avoid disturbing the surrounding sediment. The sediment sample filled a portion of the cylinder. The cylinder was then capped and the sample was given to the CDOT Materials Lab for weighing.

The volume and weight for each of the samples were determined. The unit weight was then determined by dividing the sample weight by the sample volume. The average dry unit weight from the three samples was 93.8 lb/ft^3 (1503 kg/m^3).

For the second method, a nuclear density gage was used to determine the in-situ unit weight. In October 1995, CDOT's Region 1 Construction took five representative (different locations within the basin) density gage tests in one of the sediment basins. The average of the five tests resulted in a sediment unit weight of 107.5 lb/ft^3 (1722 kg/m^3).

An average of the nuclear density gage and the cylinder results should provide a reasonable estimate of the unit weight. This average is 101 lb/ft^3 (1618 kg/m^3). This sediment unit weight is representative of what would be found in all the basins since the type of material (sanding material and cut slope sediment) is consistent from basin to basin.

The weight of sediment captured within each of the basins was determined by multiplying the unit weight of 101 lb/ft^3 (1618 kg/m^3) by the captured sediment volume. See Table 6.2.

Table 6.2
Weight of Sediment Captured by the Surveyed Basins

Sediment Basin Location	Volume of Captured Sediment - yd^3	Weight of Sediment Captured - lb
127+00	11	29,997
286+79	14	38,178
291+50	11	29,997
328+03	26	70,902
334+97	71	193,617
369+67	89	242,703
394+92	213	580,851
Total	435 yd^3 (333 m^3)	**1,186,245 lb (538,460 kg)**

6.1.2 Drainage Areas Tributary to the Sediment Basins

To estimate the amount of sediment captured in the basins that had not been surveyed, it was necessary to develop a relationship between drainage area or roadway length and the amount of sediment captured in surveyed basins. The sediment load to the un-surveyed basins will vary depending upon the drainage area size and sediment source (sanding operations or cut slopes). Table 6.3 is a summary of the pavement, cut slopes, and offsite drainage area tributary to each sediment basin. In addition, the roadway length of WB and EB I-70 is described.

Construction of the entire project had not yet been completed when the 1993 surveying efforts were undertaken. There were some drainage inlets that were plugged that were to be reopened prior to completion of the project in 1994. As a result, some of the drainage areas to the sediment basins during the surveying/monitoring period were different from what they were after construction of the project. For this reason, Table 6.3 is separated into two different categories, one for the monitoring period and one for after construction.

6.1.3 Estimated Annual Sediment Load Captured by all Basins

To estimate the annual amount of highway sand captured by the non-surveyed basins, information obtained for the basin at 328+03 was used. This basin has the longest distance of EB roadway contributing sand to it. Also, it is more toward the center of the project. This is important since the sand application rates vary depending on the basin location. Basins located more towards Eisenhower Tunnel (these are at a higher elevation) will receive more sand. Those located at a lower elevation receive less sand.

The amount of sand captured at 328+03 during the one year period was 70,902 pounds (32,184 kg). The length of EB I-70 roadway to this basin is 700 feet (213 m). Based on the annual captured weight and roadway length, the annual capture rate of sanding material per unit length of roadway is 101 lb per ft (151 kg/m) of EB roadway. It should be noted that EB I-70 has three travel lanes. The annual capture rate, in terms of pounds per acre of highway pavement (3-12 feet wide driving lanes, 4 feet inside shoulder, and 10 feet outside shoulder), is 88,300 lb/acre (99,000 kg/ha).

Some of the maintenance procedures for plowing, sweeping, and collecting sand for EB I-70 are different then they are for WB I-70. Therefore, the sediment basin capture rate of 101 pounds per foot (151 kg/m) determined for EB I-70 will not exactly match that of WB I-70. However, for the purposes of this report it is a reasonable estimate of the sand capture rate for the WB roadway lanes.

Table 6.3
Drainage Area Tributary to the Sediment Basins

	Monitoring Period - Drainage Areas						After Construction - Drainage Areas					
Basin Location	Paved DA (acres)	Road Length-EB (ft)	Road Length-WB (ft)	Cut Slope (acres)	Natural Offsite (acres)	Total DA (acres)	Paved DA (acres)	Road Length-EB (ft)	Road Length-WB (ft)	Cut slope (acres)	Natural Offsite (acres)	Total DA (acres)
401+00	n/a	n/a	n/a	n/a	n/a	n/a	1.24	0	1200	3.444	32	36.68
394+92	3.249	850	2200	5.124	70	78.37	1.544	850	550	0.82	3	5.36
382+00	n/a	n/a	n/a	n/a	n/a	n/a	2.163	1300	650	0.976	19	22.140
369+67	2.049	1200	650	1	5	8.049	2.049	1200	650	1	5	8.05
351+51	n/a	n/a	n/a	n/a	n/a	n/a	2.124	1850	0	0	0	2.124
342+06	n/a	n/a	n/a	n/a	n/a	n/a	2.226	950	1100	1.928	28	32.15
334+97	1.526	700	700	0.803	9	11.33	1.526	700	700	0.803	9	11.33
328+03	0.803	700	0	0	0	0.80	0.803	700	0	0	0	0.80
291+50	0.8	400	0	0	0	0.8	0.8	400	0	0	0	0.8
286+79	0.8	350	200	0	0	0.8	0.8	350	200	0	0	0.8
127+00	0.568	550	0	0	0	0.568	1.136	550	550	1.136	6.5	8.772

Estimate of Cut Slope Material Captured by the Surveyed Basins

Of the sediment basins surveyed, three of these had a source of material from the cut slope as well as sand from winter maintenance sanding operations. Using the 101 pounds of sanding material captured per linear foot (151 kg/m) of EB or WB I-70, it is then possible to estimate the amount of sediment captured from the cut slopes.

One thing to note is that the sediment load from the natural watershed is low relative to the loads from the cut slopes and sanding operations. Therefore, for purposes of estimating the amount of material contributed from the cut slopes, it is reasonable to ignore sediment load from the natural watershed.

As displayed in Table 6.4, the estimated average amount of sediment captured in surveyed sediment basins from cut slope areas is 58,040 lb/acre (65,100 kg/ha).

Table 6.4
Quantity of Material Captured from the Cut Slopes

Sediment Basin Location	Total Amount Captured (lb)	Cut Slope Area (acres)	Total EB and WB Road Length (ft)	(1) Amount from Sand (lb)	Sediment Amount from cut slope (lb)	Cut slope material captured (lb/acre)
394+92	580,851	5.124	3,050	308,050	272,801	53,240
369+67	242,703	1	1850	186,850	55,853	55,853
334+97	193,617	0.803	1400	141,400	52,217	65,027
				Average		**58,040 lb/acre (65,100 kg/ha)**

(1) Based on: roadway length x 101 lb/ft.

Estimated Annual Capture of all Sediment Basins

For those sediment basins where the tributary drainage area changed and for those basins that were not surveyed, basin loadings are based on the predicted highway sand capture of 101 lb/ft (151 kg/m) for EB I-70 and 101 lb/ft (151 kg/m) for WB I-70. In addition, the estimated loading from cut slope areas is based on 58,040 lb/acre (65,100 kg/ha).

For those surveyed sediment basins where the drainage areas did not change between the monitoring period and after construction, the amount of captured material is based on that found from the surveying effort.

The estimated amount of sand and sediment captured by all eleven basins annually is 985 tons (894 m-ton). Of this total amount, approximately 293 tons (265 m-ton) of sediment is captured from the cut slopes and 692 tons (627 m-ton) of sand is captured from the winter maintenance sanding operations. See Table 6.5 for a breakdown of the annual amount of sediment captured in each sediment basin.

The 985 tons (894 m-ton) of sediment captured annually is a reasonable estimate of what can be expected during the operational life of the basins. Factors that will influence the actual annual capture rate include such things as: changes in sand application rates or clean up practices (such as sweeping) by CDOT Maintenance forces, climatic conditions which will influence the amount of sand applied to the pavement, and addition or removal of controls (such as silt fence) that capture sediment from the cut slope areas.

Table 6.5
Quantity of Material Captured Annually by All Eleven Basins

Basin Location	Sanding Material (lb)	Cut Slope Sediment (lb)	Total (lb)
127+00	59,994	65,933	125,927
286+79			38,178
291+50			29,997
328+03			70,902
334+97			193,617
342+06	207,050	111,901	318,951
351+51	186,850	0	186,850
369+67			242,703
382+00	196,950	56,647	253,597
394+92	141,400	47,593	188,993
401+00	121,200	199,889	321,089
	Total annual quantity of sediment captured by all sediment basins		**1,970,804 lb (985 tons)**

Note that at station 127+00 the sanding loading was based on doubling the amount captured during the survey period. The length of roadway tributary to the basin doubled after construction. This basin is approximately 2.5 miles (4.0 km) west and approximately 1,500 feet (457 m) lower in elevation than all the other basins. Because of its lower elevation, it receives less annual precipitation that the other basins do. Consequently, less sanding material is used on the pavement up-gradient from the sediment basin. Therefore, if the 101 lb/ft (151 kg/m) per year capture rate would have been used, the amount of material captured at 127+00 would have been overestimated.

6.1.4 Basin Clean Out Cycle

During the design phase of the Straight Creek Erosion Control project, the amount of sediment captured by the basins and the basin clean out cycle were estimated. All of the basins, except the one at station 291+50, were sized for either two or five years of sediment accumulation. Since access to the basin at 291+50 was very easy, it was designed for sediment removal annually. This section compares the design clean out cycle with that which can be expected based on survey information. The clean out cycle based on the survey information should provide a more refined estimate of sediment removal requirements. Table 6.6 summarizes this information.

As can be seen from the table, the clean out cycles predicted during the design phase for most of the basins are reasonable when compared with the anticipated clean out cycle based on the survey information. The anticipated sediment removal cycle varies from once every 0.9 years at station 401+00 to once every 9.1 years at station 286+79.

The basins at 401+00 and 342+06 will require the most frequent cleaning - at a clean out cycle of 0.9 year and 1.4 years respectively. The sediment basin at 394+92 is another one to keep an eye on even though it is estimated that it will require sediment removal only once every 2.2 years. This is due to the fact that this basin captured more sediment than expected during the survey period. However, some of the runoff that was tributary to the basin during the monitoring has been diverted to another sediment basin. This should decrease the loading to the basin.

Table 6.6
Basin Clean Out Cycle

Basin Location	Design, Total Sediment Volume (ft^3)	Design, Clean Out Cycle (yr)	From Survey, Expected Annual Amount Captured (ft^3)	(1) Based on Survey, Revised Clean Out Cycle (yr)
127+00	2644 (2)	2	1247	2.1
286+79	3450	5	378	9.1
291+50	1640	1	297	5.5
328+03	2420	2	702	3.4
334+97	3020	2	1917	1.6
342+06	4290	2	3158	1.4
351+51	6210	2	1850	3.4
369+67	12600	5	2403	5.2
382+00	7120	5	2511	2.8
394+92	4180	2	1871	2.2
401+00	2630	5	3179	0.9

(1) Total design volume divided by the annual amount captured.
(2) As constructed volume, major revision to the basin geometry during construction.

The basins at stations 286+79 and 291+50 appear to be the most underutilized. These basins can accommodate additional sediment accumulation without adversely affecting the maintenance clean out cycle. Under a future project(s), runoff from additional highway drainage areas could be diverted into these basins.

Even with the above refined estimate of the necessary basin clean out cycle, it is very important to keep in mind that CDOT Maintenance forces should routinely observe the basins to assess sediment removal needs. Information provided in the October 1993 "Sediment Pond

Maintenance Report" should help Maintenance forces more accurately identify when sediment removal is required. This is especially necessary considering the facts that some of the actual constructed volumes of the basins differ from the design volumes and that the sand application rates will vary from year to year depending on the weather conditions.

6.2 Monitoring of Runoff Events

Basin inflow and outflow hydrograph data, sediment concentration data, and information on the size of sediment in the runoff was collected to determine the efficiency of the basins in removing sediment from the runoff. This data was collected for the sediment basin at station 328+03 to estimate the sediment removal efficiency of all basins. To obtain the hydrograph and sediment concentration data, a variety of monitoring measures were performed.

Monitoring of the runoff events included collection of samples to determine the concentration of sediment in both the basin inflow and outflow. The runoff flow rate and volume were also measured at the basin inflow and outflow. Finally, the size of sediment in the basin outflow was determined.

Monitoring of the basin at station 328+03 commenced on July 27, 1994 and ended on October 26, 1994. During this time, runoff and sediment concentration data was collected for:

- three rainfall events
- two simulation events
- one snowmelt event

6.2.1 Characteristics of the Sediment Basin at Station 328+03

Since the volume and release structure for each of the eleven sediment basins were designed similarly, the efficiency results determined from monitoring 328+03 should be representative of all basins. Also, the WQCV for this basin is on the low side compared with some of the other larger basins. Therefore, the WQCV will be emptied from the 328+03 basin somewhat faster than the other basins. As a result, the efficiency results obtained from monitoring may be slightly less than that of some of the other basins.

This section contains geometric and hydraulic information about the sediment basin at station 328+03. This information should be useful to fully understand the characteristics of the basin.

Figure 6.2 is a contour drawing of the basin. In addition, Table 6.7 describes the elevation, area and volume relationship of the sediment basin.

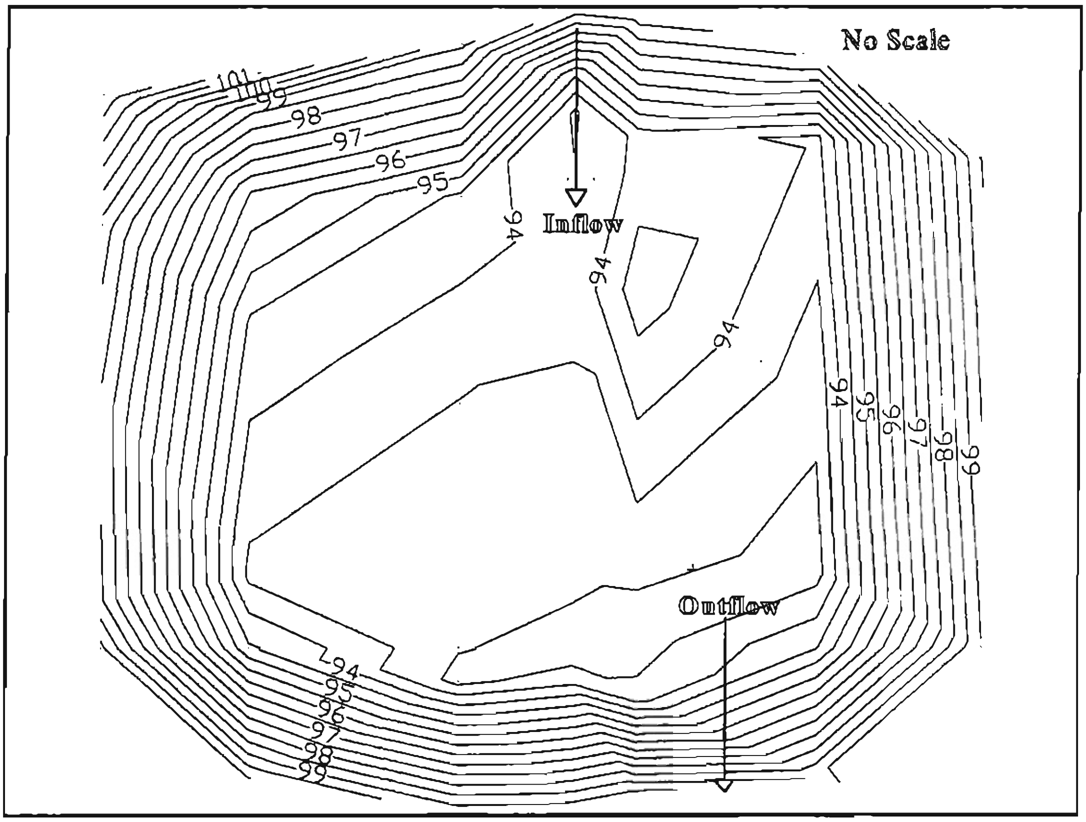


Figure 6.2: Station 328+03, Contour Map

Table 6.7
Station 328+03, Elevation-Area-Volume Relationship

Elevation (ft)	Area (ft^2)	Cumulative Volume (ft^3)
93.0	93	0
94.0	880	503
95.0	1340	1658
96.0	1550	3103
97.0	1760	4758

Figure 6.3 illustrates the riser pipe and the pipe perforations. The hydraulic performance of the riser pipe is computed using the orifice equation. This performance is summarized in Table 6.8.

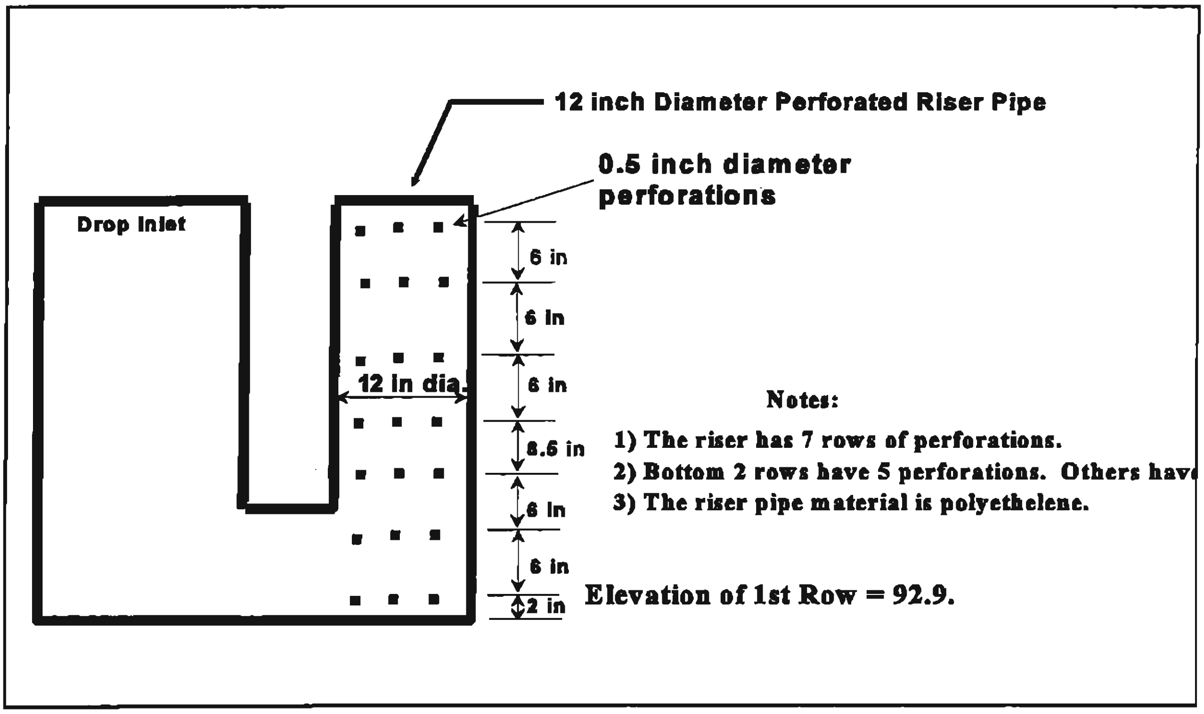


Figure 6.3: Riser Pipe

Table 6.8
Riser Pipe Hydraulics

Stage Elev. (ft)	Discharge (gpm)							
	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	Row 7	Total
92.9	0	0	0	0	0	0	0	0
93.4	8.5	0	0	0	0	0	0	8.5
93.9	13.4	8.5	0	0	0	0	0	21.9
94.3	17.0	13.4	10.2	0	0	0	0	40.6
94.9	19.9	17.0	16.1	6.2	0	0	0	59.3
95.4	22.5	19.9	20.4	14.0	6.2	0	0	83.0
95.9	24.8	22.5	23.9	18.7	14.0	6.2	0	110.1
96.4	26.9	24.8	27.0	22.5	18.7	14.0	6.2	140.1
96.9	28.8	26.9	29.7	25.7	22.5	18.7	14.0	166.4

Notes: 1) See the riser pipe figure for perforation configuration.
2) Row 1 is the lowest row of perforations. Elevation of first row is 92.9.
3) The orifice equation ($Q=C*A*(2*g*H)^{.5}$) used to compute the riser pipe discharge.
4) A=opening area, C=discharge coef., 0.6.

Using the riser pipe release discharges in Table 6.8 and the elevation-volume relationship of the constructed basin shown in Table 6.7, it is possible to compute the emptying time of the WQCV. This computation shows that the WQCV of 1310 ft^3 (37 m^3) would empty from the basin in 10.3 hours. See Table 6.9. It should be noted that this computation assumes that the WQCV entirely enters the basin before emptying begins. There is no accounting for the flow that is released during the time that the inflow hydrograph is filling the basin.

Table 6.9
Emptying Time of WQCV

Water Elevation (ft)	WQCV Released (ft^3)	Average Riser Pipe Release Rate (cfs)	Emptying Time (hr)
94.4 to 94.6	287	.0100	0.8
93.9 to 94.4	520	.0700	2.1
93.4 to 93.9	350	.0336	2.9
92.9 to 93.4	153	.0095	4.5
Totals	1310 ft^3		10.3 hours

6.2.2 Weir Calibration

A 90° v-notch weir was used as a primary flow measurement device to quantify the rate and volume of runoff entering the sediment basin at 328+03. The weir was installed inside a Type 13 inlet. This inlet was located in the concrete valley gutter along the south side of I-70. From the inlet, the runoff was conveyed into a pipe that discharged into the sediment basin. See Figure 5.1.

The hydraulic characteristics of the weir were used to compute the basin inflow rate. The standard equation for a 90° weir is:

$$Q_W = 2.5 \times H^{2.5}$$

where: Q_W = weir discharge (cfs)
H = head (ft)

The flow conditions at the weir were not ideal. Water entering the Type 13 inlet, just in front of the weir, was somewhat turbulent. Also, the small size of the inlet did not allow measurement of head at the standard distance behind the weir. Finally, sediment buildup behind the weir had potential to affect the weir hydraulics. It should be mentioned that throughout the monitoring period the weir was observed for sediment buildup. The sediment depth did reach an equilibrium point behind the weir.

To compensate for these non-ideal flow condition for weir flow, calibration of the weir equation was undertaken. This was accomplished by using the flow monitoring results from the August 26 and August 29 simulation events. These events are described in a following section.

For the simulation events, a known volume of water was discharged from a water tanker through the weir and into the sediment basin. The volume of water delivered from the water tanker was 1,069 ft^3 (30.3 m^3).

During the simulation events, the head at the weir was recorded at one minute intervals. The standard weir equation was then used to determine weir discharge. Using the computed discharge values, the event volume was then computed.

For the August 26 event, the computed volume using the standard weir equation was 904.6 ft^3 (25.6 m^3). The actual volume, 1,069 ft^3 (30.3 m^3), exceeded the computed volume by 18.2%. For the August 29 event, the computed volume using the standard weir equation was 917.5 ft^3 (26 m^3). The actual volume, 1,069 ft^3 (30.3 m^3), exceeded the computed volume by, 16.5%.

The conclusion reached was that the standard weir equation was underestimating the actual flow rate by 17.5% (average of 18.2% and 16.5%). Consequently, all computed inflow discharges for monitored events were increased by 17.5%.

6.2.3 Parshall Flume

A three inch (7.6 cm) Parshall flume was used as the primary flow measurement device to quantify the rate and volume of runoff exiting the sediment basin at station 328+03. The flume was installed near the outlet pipe which released water from the basin. Discharge from the sediment basin release pipe was conveyed through the flume. See Figure 5.1.

The hydraulic characteristics of the flume were used to compute the basin outflow rate. The three inch (7.6 cm) Parshall flume discharge equation is:

$$Q_f = 0.992 \times H_f^{1.547}$$

where: Q_f = flume discharge (cfs)
H_f = flume head (ft)

6.2.4 Sediment Concentration Analysis

Since one of the research objectives was to determine the sediment removal efficiency, sediment concentration of the basin inflow and outflow had to be determined. To accomplish this the total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS) concentrations were determined for each of the collected water-sediment samples.

Samples were collected automatically in 1 liter polyethylene bottles. Upon sample collection, each of the sample bottles was marked with sample date, time, and location. In addition, the bottles were securely capped to avoid loss of sample volume. The samples were then transported from the field back to the office where the sediment concentration was determined.

Each of the samples was logged into a record keeping system. Each of the sample bottles was assigned a number based on the location, date and sample number. For example, for the sample number 8I8/18-1, the first character 8 stands for the sediment basin at station 328+03, I designates the sample was taken at the inflow, 8/18 is the sample date, and -1 represents the first sample collected for that set of samples. In addition, the time of the sample was recorded.

The first step in the concentration analysis procedure was to determine TDS. A HACH conductivity/TDS meter was then used to determine the TDS value. A probe from the TDS meter was inserted into the sample and the TDS value was digitally displayed. The meter has a readability to 0.1 mg/l.

The sample was then shaken vigorously to uniformly distribute the sediment within the sample. Approximately 70 ml of the sample was placed into an evaporative dish. The empty weight of the dish along with the dish plus sample weight was recorded using an electronic scale. The scale, a Sartorius electronic precision balance, was used to determine sample weights. The balance, Model BA 210S, has a weighing capacity of 210 g and a readability of 0.0001 g.

The sample was then oven dried at a temperature of approximately 100 degrees Celsius. Care was taken to ensure the temperature did not exceed this value so that sample volume would not be boiled off. The dry residue weight was then determined and the TS concentration was found by the following equation:

$$TS(mg/l) = (ppm) = \frac{dryresidueweight}{water-sed.weight} \times 1{,}000{,}000$$

Finally, the sample TSS concentration was determined by subtracting the TDS value from the TS concentration.

In all, 90 samples were collected, analyzed and the results used to determine the sediment loading entering and exiting the basin. For the basin inflow 39 samples were used and at the basin outflow 51 samples were used. See Table 6.10 and Table 6.11.

Table 6.10
Water-Sediment Samples at Inflow

Sample Number	Date	Time	TDS (mg/l)	TS (mg/l)	TSS (mg/l)
8I7/31-1	Jul 31	20:30	279	1133.0	854.0
8I7/31-2	Jul 31	20:35	101	529.4	428.6
8I7/31-3	Jul 31	20:40	61.4	357.6	296.2
8I7/31-5©	Jul 31	21:00	32.9	113.1	80.2
8I7/31-7	Jul 31	21:20	29.4	93.4	64.0
8I7/31-8	Jul 31	21:30	34.1	58.4	24.3
8I7/31-9	Jul 31	21:40	45.7	84.9	39.2
8I7/31-10	Jul 31	23:20	137.4	300.4	163.0
8I7/31-13©	Jul 31	23:50	40.8	84.4	43.6
8I8/1-18©	Aug 1	00:40	32.6	61.9	29.3
8I8/1-21	Aug 1	01:10	43.3	73.7	30.4
8I8/1-22	Aug 1	01:20	48.1	69.8	21.7
8I8/9-1	Aug 9	19:35	192.4	714.5	522.1
8I8/9-2	Aug 9	19:40	172.5	553.0	380.5
8I8/9-3	Aug 9	20:20	115.3	424.4	309.1
8I8/9-4	Aug 9	20:25	65.9	304.6	238.7
8I8/9-5	Aug 9	20:35	38.4	235.2	196.8
8I8/9-6	Aug 9	20:45	29.5	351.8	322.3
8I8/9-7	Aug 9	20:55	27.6	221.1	193.5
8I8/9-8	Aug 9	21:05	25.9	362.3	336.4
8I8/9-9	Aug 9	21:15	27.3	303.0	275.7
8I8/9-10	Aug 9	21:25	30.0	115.1	85.1
8I8/18-1	Aug 18	20:15	198.8	596.8	398.0
8I8/18-2	Aug 18	20:20	135.5	332.9	197.4
8I8/18-3	Aug 18	23:50	191.8	448.3	257.0
8I8/18-4	Aug 18	23:55	132.8	299.5	166.7
8I8/18-5	Aug 18	00:25	56.8	261.5	204.7
8I8/19-6	Aug 19	00:30	31.8	159.3	127.5
8I8/19-7	Aug 19	00:40	19.1	101.0	81.9
8I8/19-8	Aug 19	01:00	16.6	28.9	12.3
8I10/8-1	Oct 8	10:16	940	11400	10460
8I10/8-2	Oct 8	10:30	778	69919	69141
8I10/8-3	Oct 8	11:00	605	54279	53674
8I10/8-4	Oct 8	11:15	573	5373.8	4800.8
8I10/8-5	Oct 8	11:30	520	15685.6	15166
8I10/8-6	Oct 8	12:00	280	2962.1	2682.1
8I10/8-7	Oct 8	12:30	190	2454.5	2264.5
8I10/8-8	Oct 8	12:45	163	2352.6	2189.6
8I10/8-9	Oct 8	13:30	187	2134.6	1947.6

Table 6.11
Water-Sediment Samples at Outflow

Sample Number	Date	Time	TDS (mg/l)	TS (mg/l)	TSS (mg/l)
8O7/31-1	Jul 31	20:45	85.4	359.4	274.0
8O7/31-2©	Jul 31	20:50	58.4	313.0	254.6
8O7/31-3©	Jul 31	21:05	43.9	205.7	161.8
8O7/31-7©	Jul 31	23:15	42.0	208.6	166.6
8O8/1-9©	Aug 1	01:15	38.7	83.7	45.0
8O8/1-11	Aug 1	02:45	38.9	85.2	46.3
8O8/9-1	Aug 9	20:40	72.0	237.8	165.8
8O8/9-2	Aug 9	20:45	59.9	196.0	136.1
8O8/9-3	Aug 9	20:50	52.9	175.6	122.7
8O8/9-4	Aug 9	21:00	45.0	130.8	85.8
8O8/9-5	Aug 9	21:10	38.0	118.8	80.8
8O8/9-6	Aug 9	21:40	30.5	115.3	84.8
8O8/9-7	Aug 9	22:40	29.0	98.6	69.6
8O8/9-8	Aug 9	23:40	31.6	251.4	219.8
8O8/19-1	Aug 19	00:40	67.5	417.5	350.0
8O8/19-2	Aug 19	00:45	54.0	222.7	168.7
8O8/19-3	Aug 19	00:55	41.8	273.1	231.3
8O8/19-4	Aug 19	01:25	27.7	290.1	262.4
8O8/19-5	Aug 19	02:25	24.5	161.3	136.8
8O8/19-6	Aug 19	03:25	24.3	400.7	376.4
8O8/19-7	Aug 19	04:25	24.7	350.3	325.6
8O8/19-8	Aug 19	05:25	26.5	293.7	267.2
8O8/26-1	Aug 26	11:00	38.3	122.7	84.4
8O8/26-2	Aug 26	11:05	38.9	138.4	99.5
8O8/26-3	Aug 26	11:15	36.6	110.3	73.7
8O8/26-4	Aug 26	11:45	35.9	104.1	68.2
8O8/26-5	Aug 26	12:36	35.9	108.6	72.7
8O8/26-6	Aug 26	12:45	35.7	129.7	94.0
8O8/26-7	Aug 26	12:47	35.1	112.7	77.6
8O8/26-8	Aug 26	12:52	34.8	101.3	66.5
8O8/26-9	Aug 26	13:02	34.4	105.0	70.6
8O8/26-10	Aug 26	13:32	34.6	92.4	57.8
8O8/26-11	Aug 26	14:32	35.6	75.6	40.0
8O8/29-1	Aug 29	09:55	39.9	171.3	131.4
8O8/29-2	Aug 29	10:00	38.9	131.4	92.5
8O8/29-3	Aug 29	10:10	36.4	132.8	96.4
8O8/29-4	Aug 29	10:36	35.2	98.1	62.9
8O8/29-5	Aug 29	10:58	34.1	77.8	43.7
8O8/29-6	Aug 29	11:03	33.9	164.0	130.1
8O8/29-7	Aug 29	11:13	33.7	82.6	48.9
8O8/29-8	Aug 29	11:43	32.9	96.0	63.1
8O8/29-9	Aug 29	12:43	32.6	96.0	63.4
8O8/29-10	Aug 29	13:43	33.1	76.8	43.7
8O8/29-11	Aug 29	14:43	34.5	132.8	98.3
8O10/8-1	Oct 8	10:37	832	9963	9131
8O10/8-2	Oct 8	10:47	834	10215	9382
8O10/8-3	Oct 8	11:35	793	8229	7436
8O10/8-4	Oct 8	11:49	772	7639	6867
8O10/8-5	Oct 8	12:49	718	5535	4817
8O10/8-6	Oct 8	13:49	655	4684	4029
8O10/8-7	Oct 8	14:30	611	4075	3464

6.2.5 Rainfall Events

The three monitored rainfall events at the basin at 328+03 occurred on July 31, 1994; August 9, 1994; and August 18, 1994.

Important to note is that the sand on the pavement, up-gradient from the sediment basin had been removed by CDOT Maintenance. Prior to monitoring of the rainfall events, they had swept the roadway and shoulder areas to remove the sanding material. Therefore, there was not a source of sand material available for transport into the basin. In addition, sanding material was not applied to the roadway during the monitoring of rainfall events.

For all three rainfall events, the TSS load was determined for both the basin inflow and outflow. The hydrograph was discretized into incremental volumes. The TSS load for the incremental runoff volume was then calculated by multiplying the sample's TSS concentration by the appropriate incremental volume. The incremental loads were then added together to determine the total event mass loading into and out of the basin.

The event mean concentration (EMC) was also calculated for the basin inflow and outflow by dividing the total mass loading by the runoff volume.

The sediment removal efficiency results were computed based on two different methods. Both methods use the principles of the Mass Balance Equation. The first method used was based on the event totals of TSS mass loading.

$$Eff.(\%) = \frac{TSSMass(inflow) - TSSMass(out)}{TSSMass(inflow)} \times 100$$

The second method used to compute the sediment removal efficiency was based on the EMCs. The sediment removal efficiency based on the total mass loading method results in a higher

$$Eff.(\%) = \frac{EMC(inflow) - EMC(out)}{EMC(inflow)} \times 100$$

sediment removal efficiency than the EMC method. This is due to the fact that much (approximately 40%) of the runoff volume entering does not exit the basin. Instead, it infiltrates into the bottom and sides of the basin. The reduced runoff volume exiting the basin results in a reduced mass of sediment leaving the basin.

The runoff depth from the drainage area for the three events ranged from 0.225 inch (0.64 cm) to 0.448 inch (1.14 cm).

Considering the fact that the size of the sediment transported into the basin was small (there was no sanding material available for transport - it had been swept by CDOT Maintenance), the basin showed good removal efficiency for the July 31 and August 9 event. The TSS removal efficiency, based on storm mass loading, was 55.5% and 72.1% for the July 31 and August 9 events respectively.

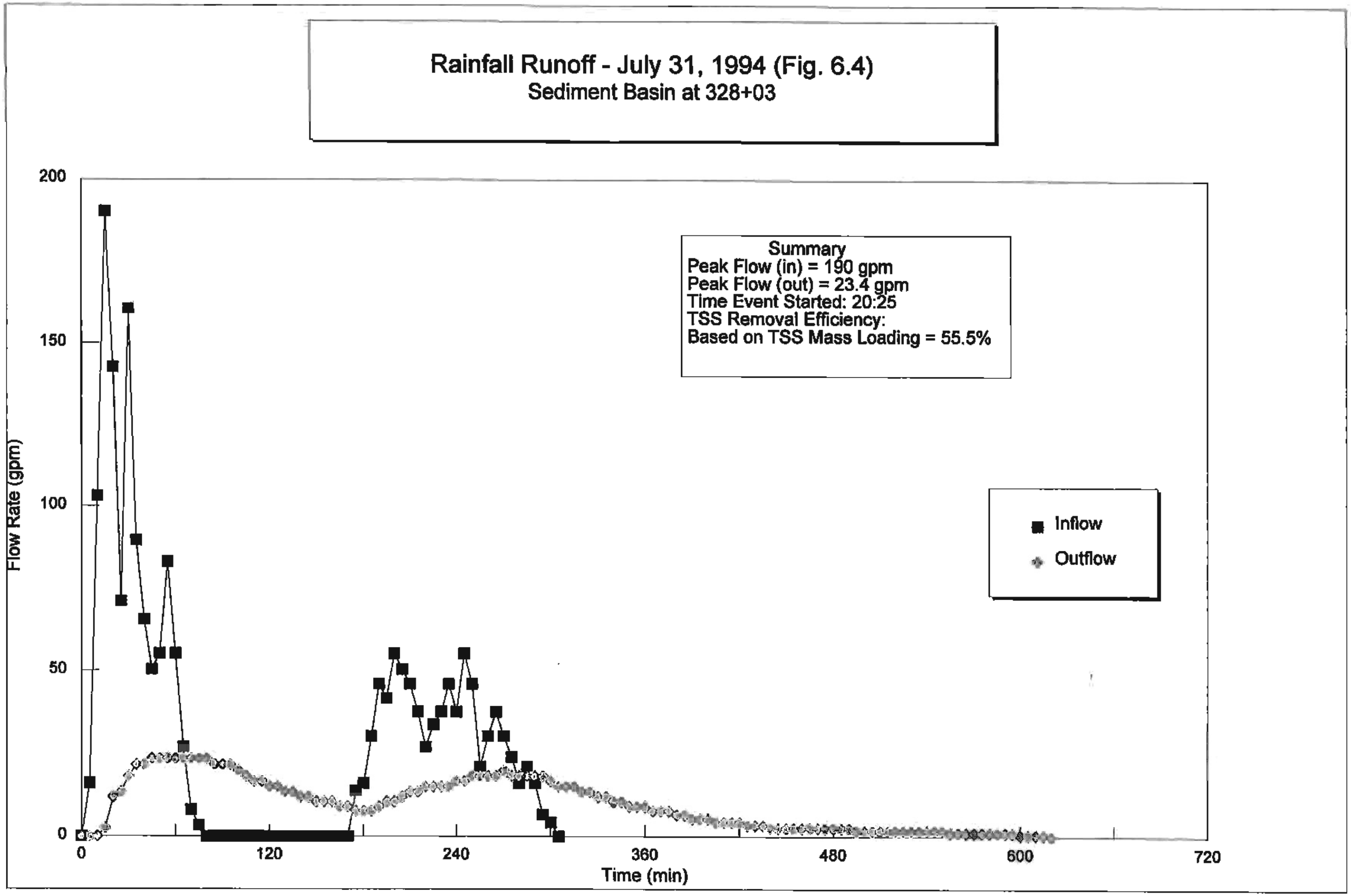
On the other hand, the basin performed poorly for the August 18 event. The basin actually had a negative efficiency for this event. The total load that entered the basin was 2,209 g and 4,265 g actually left the basin.

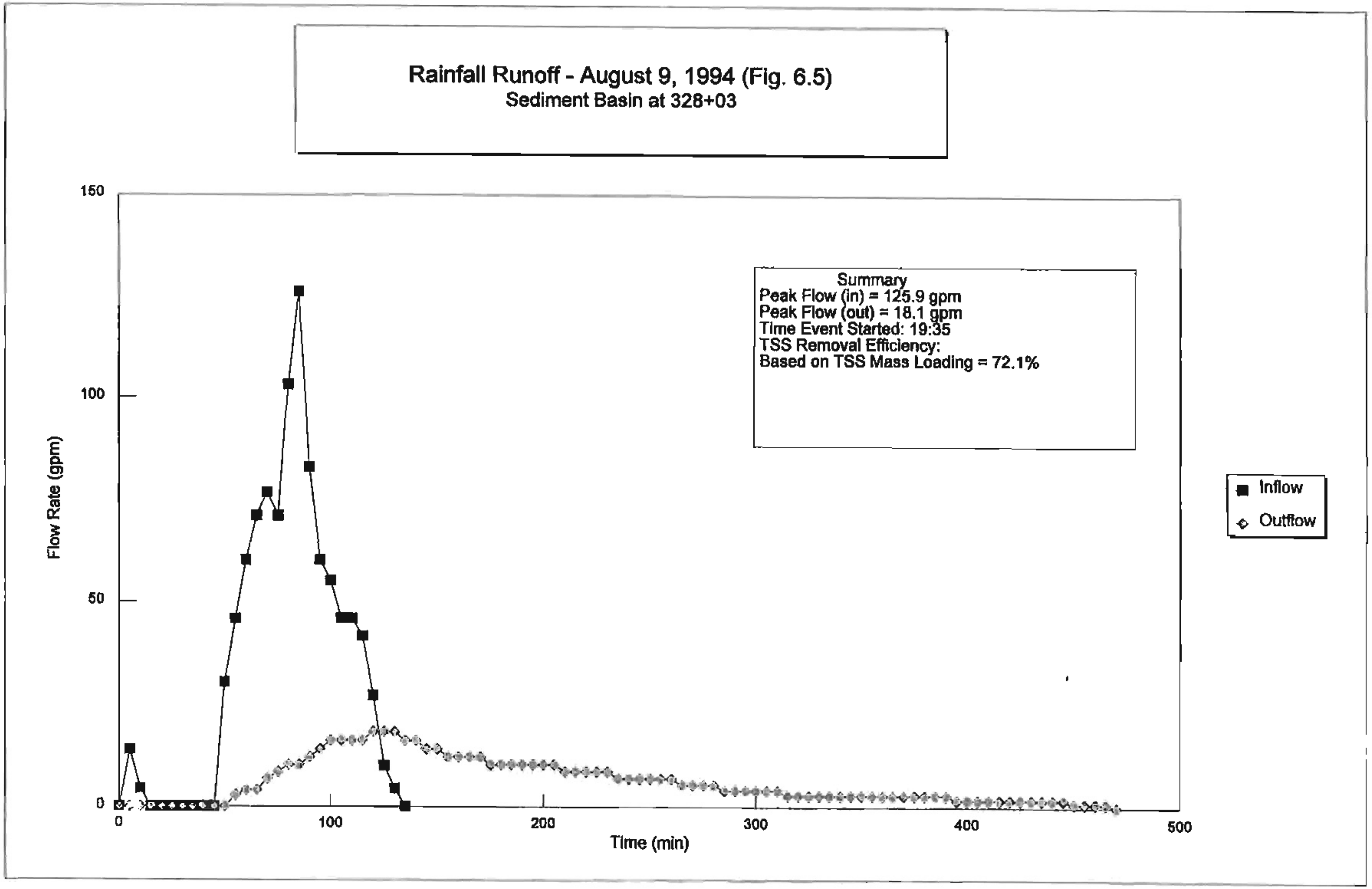
All measured sample TSS concentrations for runoff leaving the basin for the August 18 event were typically higher than the other rainfall events. Also, the EMC for the outflow was 255.3 mg/l. This is much higher than the other two events. One possible reason for the outflow sediment concentration being so high was maybe there was some erosion of the slope adjacent to the basin. The eroded material could have been transported into the basin causing high TSS concentrations thereby giving unexpectedly high concentration in the outflow.

The basin total TSS mass inflow for the three rainfall events was 12,946 g. Total TSS mass leaving the basin was 8,261 g. Based on the total mass loading, the basin sediment removal efficiency for the three events was 36.2%. A description of basin inflow, outflow, infiltration, sediment loading, and sediment removal efficiency is provided in Table 6.12. In addition, Figures 6.4 - 6.6 illustrate the inflow and outflow hydrographs for each of the rainfall events.

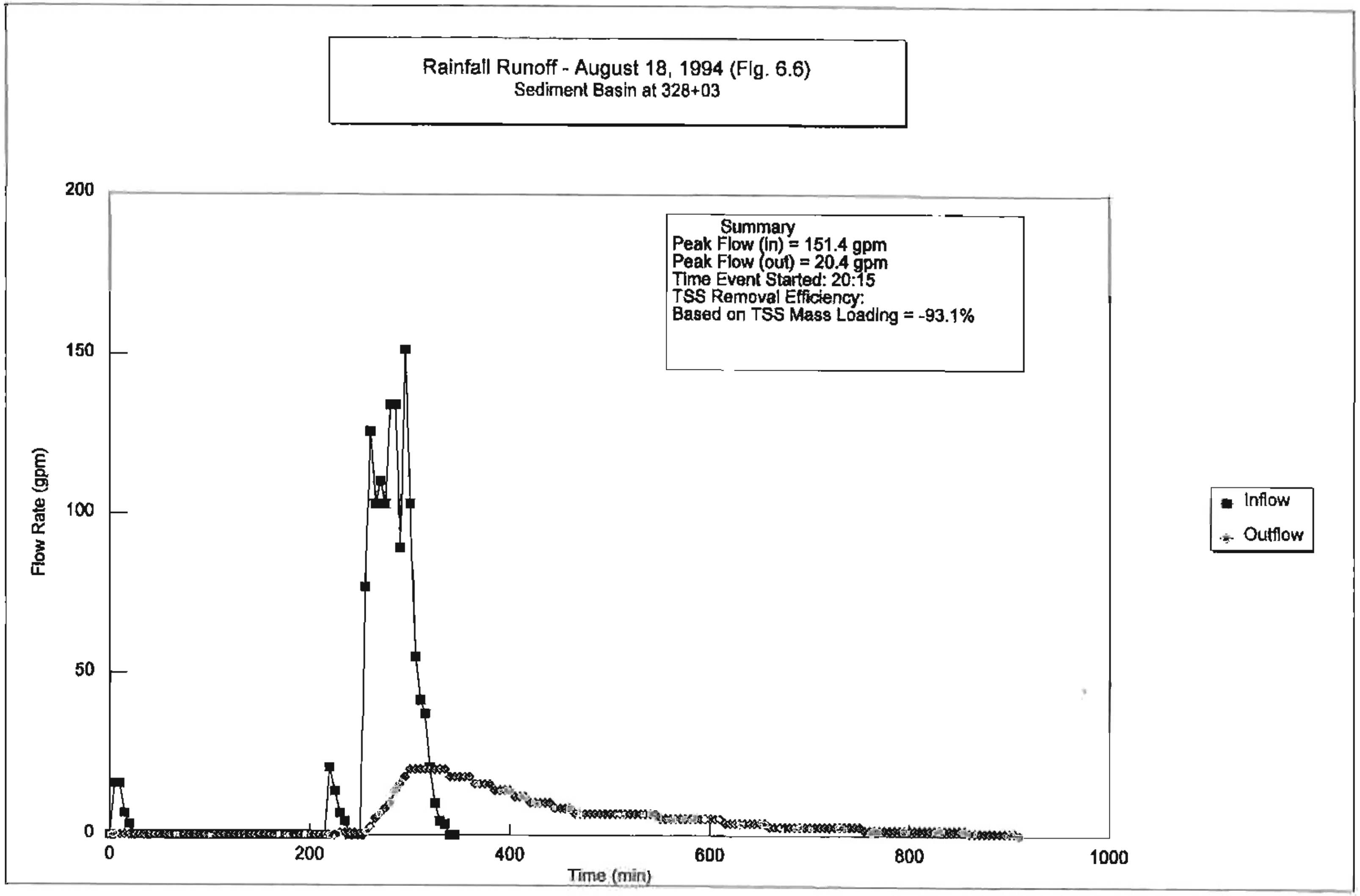
Table 6.12
Rainfall Events - Summary Information

Characteristic	Jul 31, 1994	Aug 9, 1994	Aug 18, 1994
Basin Inflow			
Start Time	20:25	19:35	20:15
End Time	01:30	21:45	01:50
Actual Inflow Time	3 hr & 35 min	1 hr & 40 min	2 hr & 30 min
Volume	1302 ft^3	652 ft^3	931 ft^3
Effective Precipitation	0.448 in	0.225 in	0.321 in
Peak Flow	190 gpm	125.9 gpm	151.4 gpm
No. of Samples Taken	12	5	8
Basin Outflow			
Start Time	20:40	20:25	00:00
End Time	6:45	03:20	11:20
Duration of Release	10 hr & 5 min	6 hr & 55 min	11 hr & 20 min
Volume	808 ft^3	371 ft^3	590 ft^3
Peak Flow	23.4 gpm	18.1 gpm	20.4 gpm
No. of Samples Taken	6	8	8
Basin Infiltration			
Infiltration	494 ft^3	282 ft^3	341 ft^3
Percent Infiltration	37.9%	43.2%	36.7%
Sediment Loading			
TSS Load (in)	6,036 g	4,702 g	2,209 g
TSS Load (out)	2,683 g	1,313 g	4,265 g
TSS EMC (in)	163.8 mg/l	254.7 mg/l	83.8 mg/l
TSS EMC (out)	117.3 mg/l	125.2 mg/l	255.3 mg/l
Removal Efficiency			
Based on EMC	28.4%	50.8%	-204.6%
Based on Mass Load	55.5%	72.1%	-93.1%


Rainfall Runoff - July 31, 1994 (Fig. 6.4)
Sediment Basin at 328+03
Summary
Peak Flow (in) = 190 gpm
Peak Flow (out) = 23.4 gpm
Time Event Started: 20:25
TSS Removal Efficiency:
Based on TSS Mass Loading = 55.5%
Inflow
Outflow
Flow Rate (gpm)
Time (min)
200
150
100
50
0
0
120
240
360
480
600
720



Rainfall Runoff - August 9, 1994 (Fig. 6.5)
Sediment Basin at 328+03


Rainfall Runoff - August 18, 1994 (Fig. 6.6)
Sediment Basin at 328+03
Summary
Peak Flow (in) = 151.4 gpm
Peak Flow (out) = 20.4 gpm
Time Event Started: 20:15
TSS Removal Efficiency:
Based on TSS Mass Loading = -93.1%
Flow Rate (gpm)
200
150
100
50
0
0
200
400
600
800
1000
Time (min)
Inflow
Outflow

It should be pointed out that the TSS EMC inflow values for the three events are fairly typical of highway runoff (without a high source of sanding material). The EMC inflow was 158.3 mg/l. For comparison purposes, the I-70/I-25 monitoring that was completed as part of a Federal Highway Administration study resulted in a TSS of 344.7 mg/l. In addition, the TSS values obtained from the CDOT monitoring of I-225 highway runoff were even higher at 1419 mg/l. These higher values illustrate that there was no sand being transported into the basin from the tributary drainage area during the rainfall events.

6.2.6 Simulation Events

The months of the monitoring period were July through October. During this period, the snowfall, ice, and temperature conditions do not require the application of much sanding material. Instead, the vast majority of sanding material is applied between the months of November and May. Monitoring of the basins would be very difficult during the winter and spring. The snowpack usually remains until late spring. This makes access to the basins difficult for both sample collection and runoff data collection. In addition, freezing temperatures would cause operating problems with the automatic sampling equipment. This is because water in the sampler intake line would freeze preventing samples from being collected.

It was necessary to simulate conditions where sand was available for transport since monitoring of the basins during the winter months would be very difficult and since CDOT maintenance had swept and removed the sand on the roadway.

The simulation involved using a water tanker to deliver water into the basin. Sand was mixed into this water after it was discharged from the tanker. CDOT Maintenance provided the water tanker. The 4,000 gallon (15.1 m^3) tanker was parked uphill from the drop inlet leading to the basin. A valve on the tanker was opened and water was released into a concrete gutter. This water flowed into the drop inlet. At this point sand was added to the water. The sand-water mixture was then conveyed into a pipe that discharged into the sediment basin.

The 4,000 (15.1 m^3) gallon water tanker was emptied in approximately 40 minutes. The tanker was then driven to the West Portal of Eisenhower Tunnel to be refilled. Upon returning to the site another 4,000 (15.1 m^3)gallons were delivered into the basin. Approximately one hour elapsed between the time the first tanker was emptied and the beginning of emptying the second tanker.

Two simulation events, one on August 26, 1994 and the other on August 29, 1994 were implemented. Two full tankers were used for each event. In all, 8,000 gallons (30.3 m^3) were delivered into the basin for each simulation.

A target EMC of 3,000 mg/l was selected for the inflow into the basin. To accomplish this 200 pounds of sand was added to the water entering the basin. The 200 pounds (90.8 kg) of sand was input into the water throughout the entire duration of the event. It should be noted that TS was used for determining efficiency rather than TSS since the total weight for the sediment entering the basin was known. The fraction that was dissolved or suspended was not determined.

The basin showed excellent removal efficiency for the sanding material. The efficiency based on the average TS mass sediment loading for the two events was 98.6%. The average efficiency based on TS EMCs was 96.6%.

One interesting thing to note was the high amount of infiltration. The average percent of inflow that infiltrated into the basin floor was 63%. This is higher than the 40% infiltrated during the rainfall events. This is probably due to the fact that the antecedent moisture condition was higher for the rainfall events than during the simulation event. This would result in less infiltration during the rain events. In addition, during rain events there is some runoff contribution into or on the basin that does not go through the basin inflow monitoring point. For example, precipitation that falls directly on the basin adds volume to the basin outflow. Runoff into the basin from the basin's slopes also adds to the outflow volume. Both of these factors help explain why the infiltration percentage was less for rainfall events than for the simulation events.

A description of the basin inflow, outflow, infiltration, and sediment loading, and sediment removal efficiency is provided in Table 6.13. In addition, Figures 6.7 and 6.8 illustrate the inflow and outflow hydrographs for the simulation events.

6.2.7 Snowmelt Event

Snowfall occurred during the afternoon and evening of October 7, 1994 and sanding material was applied to the roadway. The temperatures warmed on October 8, 1994 and the snow began to melt at about 10:00 A.M..

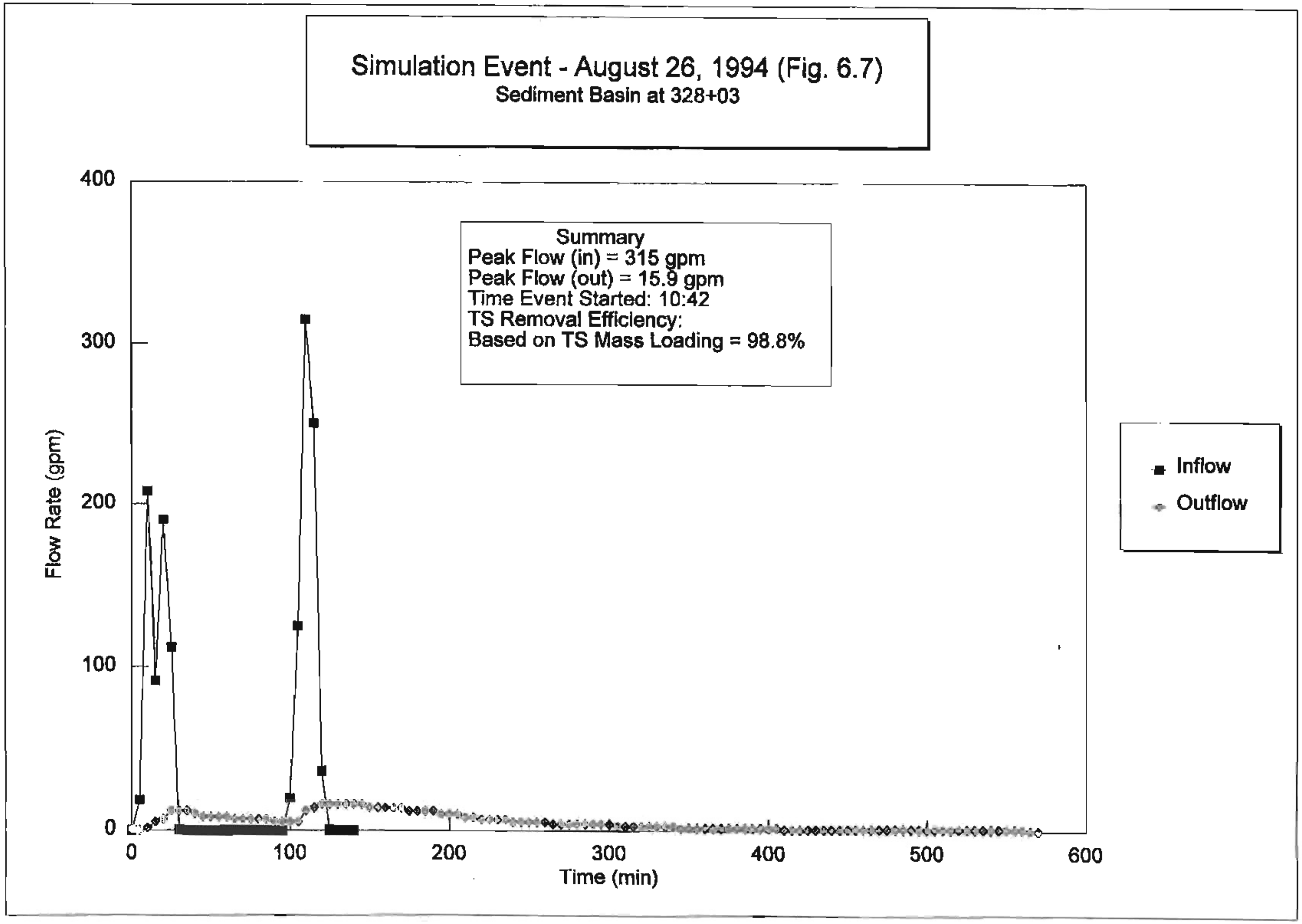
For the snowmelt event the basin showed very good removal efficiency. The efficiency based on the TSS mass loading was 95.2%. The efficiency based on TSS EMCs was 85.4%.

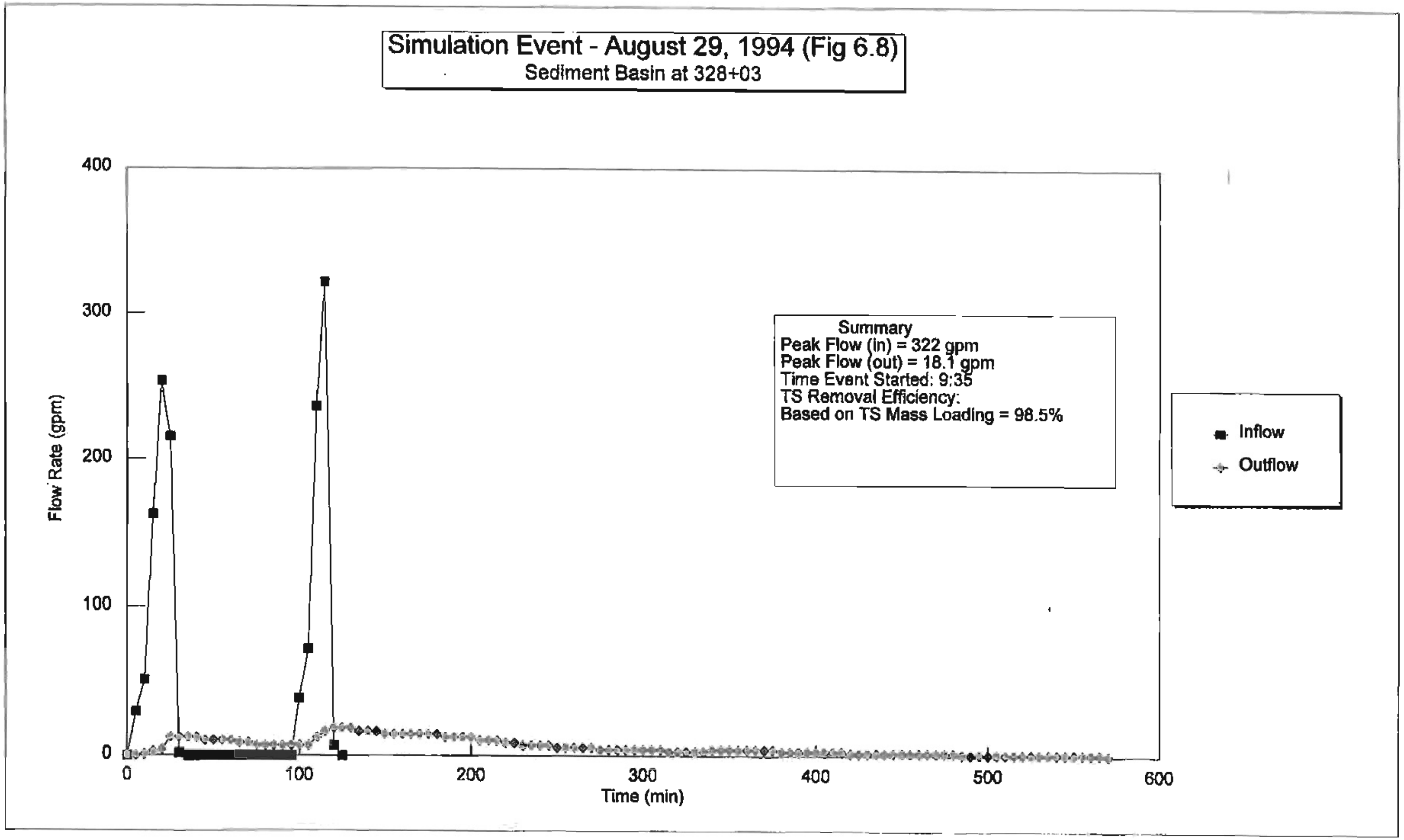
The amount of sand transported into the basin was very large compared to the rainfall and simulation events. For example, 385,000 g of sand was transported into the basin during the one snowmelt event as compared to only 13,000 g for all three rainfall events. The mass of material transported into the basin for the snowmelt was 30 times more than the rainfall event.

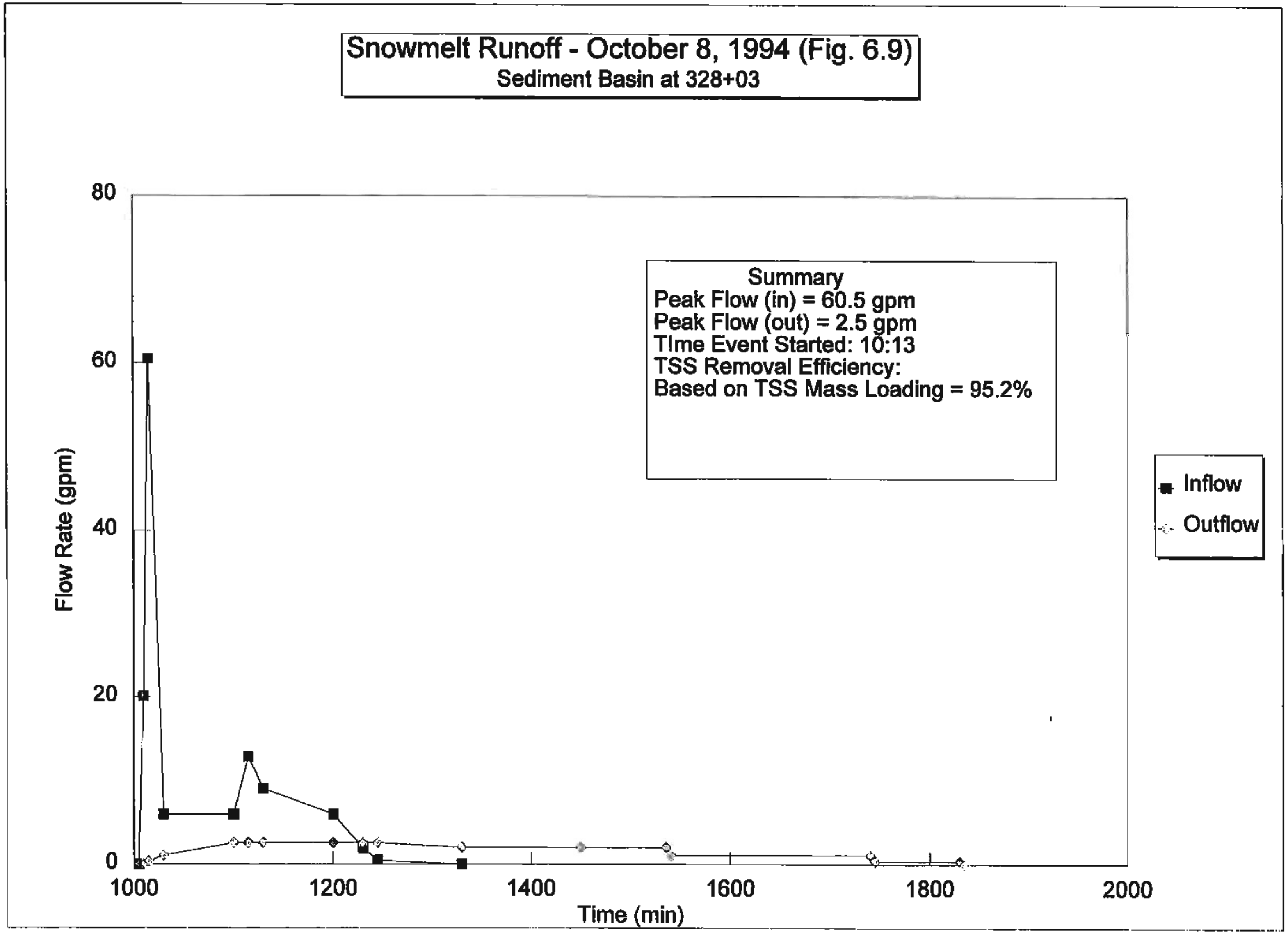
A description of the basin inflow, outflow, infiltration, sediment loading, and sediment removal efficiency is provided in Table 6.13. In addition, Figure 6.9 illustrates the inflow and outflow hydrograph for the snowmelt event.

Table 6.13
Simulation and Snowmelt Events - Summary Information

Characteristic	Aug 26, 1994 Simulation Event	Aug 29, 1994 Simulation Event	Oct 8, 1994 Snowmelt Event
Basin Inflow			
Start Time	10:42	9:35	10:13
End Time	12:59	11:36	14:50
Actual Inflow Time	1 hr & 9 min	0 hr & 59 min	4 hr & 37 min
Volume	1069 ft^3	1069 ft^3	348 ft^3
Effective Precipitation	0.368 in	0.368 in	0.120 in
Peak Flow	315 gpm	322 gpm	60.5 gpm
No. of Samples Taken	n/a	n/a	9
Basin Outflow			
Start Time	10:50	9:40	10:15
End Time	20:05	19:00	18:35
Duration of Release	9 hr & 15 min	9 hr & 20 min	8 hr & 20 min
Volume	388 ft^3	442 ft^3	114 ft^3
Peak Flow	15.9 gpm	18.1 gpm	2.5 gpm
No. of Samples Taken	11	11	6
Basin Infiltration			
Infiltration	682 ft^3	627 ft^3	234 ft^3
Percent Infiltration	63.8%	58.7%	67.2%
Sediment Loading			
TSS Load (in)	90,800 g (TS)	90,800 g (TS)	384,645 g
TSS Load (out)	1,063 g (TS)	1,330 g (TS)	18,383 g
TSS EMC (in)	3,001 mg/l	3,001 mg/l	39,040 mg/l
TSS EMC (out)	96.9 mg/l	106.3 mg/l	5,694 mg/l
Removal Efficiency			
Based on EMC	96.8%	96.5%	85.4%
Based on Mass Load	98.8%	98.5%	95.2%


Simulation Event - August 26, 1994 (Fig. 6.7)
Sediment Basin at 328+03
Summary
Peak Flow (in) = 315 gpm
Peak Flow (out) = 15.9 gpm
Time Event Started: 10:42
TS Removal Efficiency:
Based on TS Mass Loading = 98.8%
Flow Rate (gpm)
0
100
200
300
400
0
100
200
300
400
500
600
Time (min)
Inflow
Outflow


Simulation Event - August 29, 1994 (Fig 6.8)
Sediment Basin at 328+03
Summary
Peak Flow (in) = 322 gpm
Peak Flow (out) = 18.1 gpm
Time Event Started: 9:35
TS Removal Efficiency:
Based on TS Mass Loading = 98.5%
Inflow
Outflow
Flow Rate (gpm)
Time (min)
0
100
200
300
400
500
600



Snowmelt Runoff - October 8, 1994 (Fig. 6.9)
Sediment Basin at 328+03
Summary
Peak Flow (in) = 60.5 gpm
Peak Flow (out) = 2.5 gpm
Time Event Started: 10:13
TSS Removal Efficiency:
Based on TSS Mass Loading = 95.2%
Inflow
Outflow
Flow Rate (gpm)
Time (min)
0
20
40
60
80
1000
1200
1400
1600
1800
2000

6.3 Size of Sediment

As was mentioned above, the sources of sand and sediment transported into the basins are from maintenance sanding operations and from the cut slopes. To better understand the particle size distribution of the source materials, several soil samples were collected. A sieve analysis was performed by the CDOT Materials Lab for each sample. Figure 6.10, below, displays the gradation results.

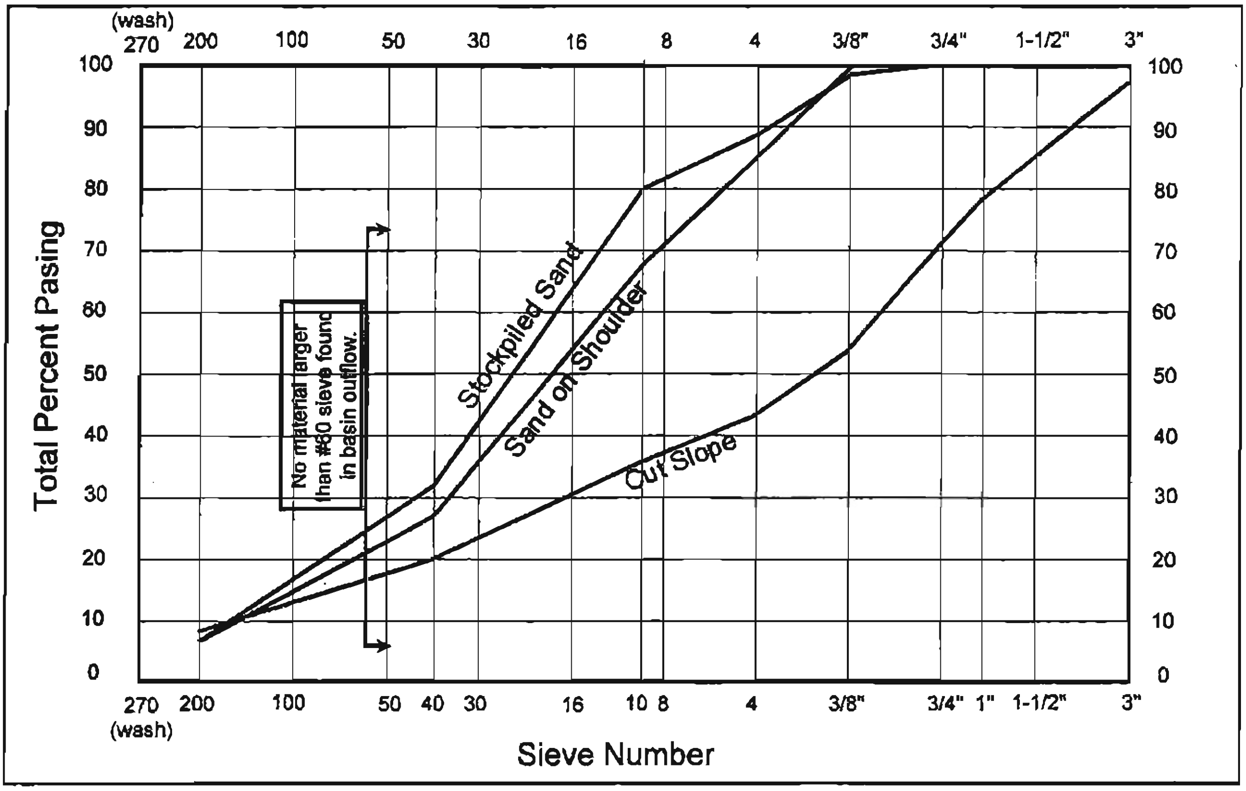


Figure 6.10: Particle Size of Source Material

Represented on the figure is cut slope material taken approximately 10 feet above the roadway at station 395+00, accumulated sand along the outside shoulder of eastbound I-70 near station 287+00, and stockpiled sand prior to being used.

As can be seen, the size of the particles from the cut slope is larger than the shoulder or stockpile areas. Notice that only 55% of the cut slope material passes the 3/8 inch (9.5 mm) sieve. Whereas 100% of the shoulder and stockpiled sand pass the 3/8 inch (9.5 mm) sieve.

Another thing to point out is that the shoulder sand material appears to be slightly larger than the stockpile material. This is probably due to the fact that runoff has washed the fine grain material out of the sand that is deposited along the shoulder.

The size of material exiting the basin in the discharge through the release structure was also determined. This information is summarized in Table 6.14.

Table 6.14
Size of Material in Basin Outflow

Type of Event	Sieve Number - Percent Passing							
	#45	#60	#80	#100	#120	#170	#200	#230
Rainfall	100	100	98	97	96	95	95	94
Simulation	100	100	94	93	91	91	90	89
Snowmelt	100	100	75	53	24	11	10	6

Table 6.4 shows that the size of sediment found in the outflow release did not exceed the #60 sieve (0.25 mm). This is true for the rainfall, simulation, and snowmelt runoff events.

The fact that no material left the basin larger than the #60 (0.25 mm) sieve can be evaluated against the size of the source material. This can be done to assess the percentage of the source material that would be captured in the basin. Such a comparison shows that at least 78 percent (approx. 22 percent is smaller than the #60 (0.25 mm) sieve) of the source material should be intercepted and captured by the sediment basins. See Figure 6.10.

7.0 Overall Sediment Removal Efficiency

Ideally, it would have been preferred to monitor all runoff events that entered and left the sediment basin at station 328+03 for an entire year or more. However, due to weather, budget, and manpower constraints - it was not possible to obtain such extensive data. In addition, the results obtained from the completed monitoring will provide a reasonable estimate of the overall annual sediment removal efficiency of the basin.

The results from the six monitored runoff events were used to estimate the overall annual sediment basin removal efficiency. Monitored runoff events included: the three summer rainfall events, the two events to simulate conditions when sand is available for transport, and the one snowmelt event. They represent both rainfall and snowmelt conditions and should provide a reasonable estimate of annual sediment basin removal efficiency.

It is important to note that there was no sanding material transported into the basin during the rainfall events since the sand had been swept and removed from the pavement by CDOT Maintenance. Therefore, the TSS load and EMC values for the rainfall events were much lower than the other events.

To illustrate this fact, the TSS loads generated by the summer rainfall events and by the snowmelt event can be compared. For all three rainfall events, only 29 lb (13 kg) of sediment was transported into the basin. In comparison, for just one snowmelt event (October 8, 1994), 847 lb (385 kg) was transported into the basin. The single snowmelt event produced 30 times more material than did all three rainfall events. Therefore, the sediment removal performance of the basin during the snowmelt event should, and will, significantly influence the overall annual sediment removal efficiency.

Table 6.15 summarizes the loading for all the events.

Table 6.15
Sediment Loading for All Monitored Events

Type of Event Monitored	TSS Load Into the Basin (g)	TSS Load Out of the Basin (g)	TSS EMC Into the Basin (mg/l)	TSS EMC Out of the Basin (mg/l)
Rainfall Events				
July 31, 1994	6,036	2,683	163.8	117.3
August 9, 1994	4,702	1,313	254.7	125.2
August 18, 1994	2,209	4,265	83.8	255.3
Simulation Events				
August 26, 1994	90,800 (TS)	1,063 (TS)	3,001 mg/l (TS)	96.9 (TS)
August 29, 1994	90,800 (TS)	1,330 (TS)	3,001 mg/l (TS)	106.3 (TS)
Snowmelt Event				
Oct 8, 1994	384,645	18,383	39,040	5,694
Total TSS Mass Load	**579,192 g**	**29,037 g**	**Efficiency based on total load: (579, 192 - 29,037)/579,192 = 95%.**	
Ave. TSS EMC	**Efficiency based on EMC: (7,591 - 1,066)/7,591 = 86%.**		**7,591 mg/l**	**1,066 mg/l**

The efficiency of the sediment basin in removing sediment from the runoff was computed based on the principles of the Mass Balance Equation. The overall efficiency for based on both the total TSS mass load and the average TSS EMC is:

- Efficiency (based on mass load) = 95.0%
- Efficiency (based on EMC) = 86.0%
- Efficiency (ave. of mass load & EMC) = 90.5%

At the time of monitoring, the efficiency results based on the mass load are the most accurate. This is because the infiltration rate into the basin bottom is high and it has a significant influence on the amount of sediment that exits the basin. Computation of efficiency based on the load entering and leaving the basin more accurately accounts for this infiltration.

However, as time goes by the sediment deposited within the basin will tend to seal the basin bottom. Consequently, there will be less infiltration. As a result, the sediment removal efficiency will move towards that value estimated by the EMC method. For the purposes of this study, it is reasonable to use the average of the mass load and EMC method to estimate the sediment removal efficiency. Therefore, the overall annual TSS removal efficiency for the sediment basin at station 328+03 is 90.5%.

8.0 Sediment Load into Straight Creek from the Basins

To answer the question - how much sediment load is contributed to Straight Creek from the sediment basins, two things have to be known. First, the amount of sand captured by the basins has to be quantified. Second, the efficiency of the basins in removing sediment from the runoff has to be quantified. Both of these items were determined as part of this research.

As far as the quantity amount of sand captured by the basins, in Section 6.1.3 it was estimated that 985 tons (894 m-ton) of sand and sediment would be captured annually by the eleven sediment basins.

As far as the sediment removal efficiency, it is reasonable to use the efficiency results obtained for the monitoring of the sediment basin at station 328+03. In Section 7.0, it was estimated that the 90.5% of sediment (TSS) entering the basin would be removed. It is reasonable to use this efficiency for all eleven basins for a couple of reasons.

First, the design of all sediment basins was similar. All eleven basins were designed to capture runoff from a 0.5 inch (1.27 cm) precipitation event. In addition, extra volume was included in each basin for sand and sediment storage. The depth of all the basins was set at four feet (1.2 m) for runoff and sediment storage. Finally, the release structure, which slowly meters runoff out of the basins, was designed the same for all basins.

Second, the source and type of material entering the basins doesn't change that much from basin to basin. The type and size of sanding material applied to the road for vehicle traction purposes does not vary since it's physical properties are designated by CDOT Maintenance specifications. Therefore, because the physical properties are uniform, the sand will settle out of the runoff at the same rate from basin to basin. Also, the size of particles from the I-70 cut slope are somewhat similar to the sanding material. In fact, according to Figure 6.10, the cut slope material size is larger than the sand and subsequently should settle at a somewhat faster rate.

To estimate the annual sediment load that enters the basin, the annual amount captured - 985 tons (894 m-ton) is divided by the sediment removal efficiency - 90.5%. To determine the annual amount leaving the basins and entering Straight Creek, the load captured by the basins is subtracted from the load that enters the basins.

- Annual Load that Enters the Basins (985 tons / 90.5%) = 1,088 tons
- Annual Load Captured by the Basins = 985 tons
- Annual Load that Enters Straight Creek from the Basins = 103 tons

9.0 Cost Analysis

The question that will be addressed in this section is the cost of implementing the sediment basins. On an annual basis, the sediment basins will prevent approximately 985 tons (894 m-ton) of sand and sediment from entering the creek. This section describes how much money, in terms of construction dollars, was required to reduce the Straight Creek sediment loading by 985 tons (894 m-ton) per year.

The sediment basin construction costs described below include cost for both the construction of the basins and construction of the maintenance access road.

Sediment basin features constructed and included in this cost analysis include: embankment material, the release structure, outlet pipe, structure excavation, structure backfill, loose riprap, geotextile, and grouted riprap. In addition, a percentage of the project costs for mobilization, clearing and grubbing and construction surveying was also included in the basin cost. It should be pointed out that costs for the fill slope pipe rundowns and for construction of the drainage collection system along the I-70 shoulder were not included in the basin cost. Cost for sediment basin construction was $367,325.

In 1995, construction of a maintenance access road was started. The access road project is to be completed in the spring of 1996. The entire cost for this project, based on the contractor's bid is $497,655.

Total cost for sediment basin and access road construction is $864, 980. The average cost for the eleven basins is $78,635 per basin.

If a 25-year life of the sediment basins is assumed, 24,625 tons (22,339 m-ton) of sand and sediment material will have been captured. The unit cost (excludes maintenance costs) to capture this material would be $35/ton ($864,980/24,625 tons) ($39/m-ton).

The construction costs for the basins were higher than what would be expected for similar work on a less challenging site. This is due to a number of factors. Delivery and use of equipment and materials for the construction of these basins was very difficult since there was no access from the bottom of the fill slope. All construction efforts had to be staged from the shoulder of I-70 and the sediment basins were 300 feet (90 m) down the 1:1 fill slope. Finally, the construction season duration is shorter than most locations because of weather conditions.

It should be pointed out that the cost of construction of additional basins in this project area will be significantly less. This is due to the fact that an access road will be available to deliver equipment, materials and labor directly to a location for basin construction. In addition there will be no cost for maintenance road construction since it will have already been built.

10.0 Conclusions

A number of conclusions can be drawn as a result of this research. Most of the following conclusions are described based on the research objective that they support.

Research Object. 1: Quantify the amount of sand captured by the sediment basins.

Conclusion: Based on the surveying efforts and the relationship developed between drainage area and amount of sediment captured, it is estimated that 985 tons (894 m-ton) of sand and sediment are captured annually by the eleven sediment basins.

Research Object. 2: Determine the efficiency of the basins in removing sediment from runoff.

Conclusion: The efficiency of the sediment basins in removing sediment from runoff was based on monitoring sediment loading at the sediment basin at station 328+03 for a number of runoff events. The calculated TSS removal efficiency is 90.5%. In other words 90.5% of all sand and sediment that enters the basins will be captured.

Research Object. 3: Determine the quantity of sediment released from the basins into Straight

Creek.

Conclusion: The quantity of sediment released into Straight Creek from the basins was determined based on the calculated removal efficiency and the annual quantity of sediment captured in the basins. On an annual basis a total of 1,088 tons (987 m-ton) will enter the basins. Of this amount, 985 tons (894 m-ton) will be intercepted and captured within the basins. And 103 tons (93.4 m-ton) will be conveyed through the basins into Straight Creek. Therefore, sand and sediment loading into Straight Creek was reduced from 1,088 tons (987 m-ton) per year to 104 tons (93.4 m-ton) per year as a result of construction of the sediment basins.

Research Object. 4: Quantify the sediment loading differences between pavement and cut slope areas.

Conclusion: Based on the surveying efforts it was estimated that 101 pounds of sanding material per linear foot of highway (151 kg/m) for EB I-70 and 101 pounds of sanding material per linear foot of highway (151 kg/m) for WB I-70 would be captured annually by the sediment basins. In terms of pounds per acre of highway pavement, the estimated sand capture rate is 88,300 lb/acre (99,000 kg/ha).

In addition, it was estimated that 58,040 pounds per acre (65,100 kg/ha) of sediment from the cut slopes would be captured annually by the sediment basins.

Research Object. 5: Refine the estimate of the required maintenance clean out cycle.

Conclusion: The clean out cycles predicted during the design phase of the Straight Creek Erosion Control project for most of the basins were found to be reasonable when compared with the anticipated clean out cycle based on the survey information. Based on the surveyed information, the anticipated sediment removal cycle varies from once every 0.9 years at station 401+00 to once every 9.1 years at station 286+79.

Even with the refined estimate of the necessary basin clean out cycle, it is very important to keep in mind that CDOT Maintenance forces should routinely observe the basins to assess sediment removal needs. Information provided in the October 1993 "Sediment Pond Maintenance Report" should help Maintenance forces more accurately identify when sediment removal is required. This is especially necessary considering the facts that some of the actual constructed volumes of the basins differ from the design volumes, that the sand application rates will vary from year to year depending on the weather conditions, and that maintenance practices may vary.

Other conclusions reached as a result of the research are:

- An analysis of the size of sediment in the runoff exiting the basin was completed. This showed that for all rainfall, simulation, and snowmelt events: no material larger than #60 (0.25 mm) sieve left the basin.

- The total cost to construct the basins and the anticipated cost to build the access road is $864,980. Assuming a 25-year life for the basins, the unit cost to capture the sanding and sediment material is $35/ton ($39/m-ton). Maintenance costs were not included.

References

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6) *Urban Storm Drainage Criteria Manual, Volume 3, Best Management Practices,* Urban Drainage and Flood Control District, September 1992.