TECHNICAL SERVICE CENTER
Denver, Colorado

Sediment Impact Analysis of the Removal of Coleman, South, and Wildcat Diversion Dams on South and North Fork Battle Creeks

Battle Creek Salmon and Steelhead Restoration Project, California

Prepared by

Technical Service Center

U.S. Department of the Interior
Bureau of Reclamation

April 2001

RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DEPARTMENT OF THE INTERIOR'S MISSION

As the nation's principal conservation agency, the Department of the Interior is charged with the mission:

- to encourage and provide for the appropriate management, preservation, and operation of the Nation's public lands, and natural resources for benefit and enjoyment by all Americans both now and in the future;
- to develop and use resources in an environmentally sound manner and provide an equitable return on these resources to the American taxpayer;
- to carry out related scientific research and investigations in support of these objectives;
- and to carry out trust responsibilities of the U.S. Government with respect to American tribes and Alaska Natives.

APPROVAL SIGNATURES

This report was prepared by the following persons in the Technical Service Center (TSC) of the Bureau of Reclamation:

Blair P. Greimann, Sedimentation and River Hydraulics

Peer review was performed by the following TSC personnel:

Cassie C. Klumpp

Cassie Klumpp, Sedimentation and River Hydraulics Group

ACKNOWLEDGMENTS

The following persons contributed information for this report:

U.S. Bureau of Reclamation

Jim Goodwin (Sacramento, CA)	(916) 978-5316
Dave Gore (Sacramento, CA)	(916) 978-5308
Micheal McCulla (Sacramento, CA)	(916) 978-5307
Joel Sturm (Sacramento, CA)	(916) 978-5305

California Department of Water Resources

Scott Kennedy (Red Bluff, CA)	(530) 529-7371
Bill Mendenhall (Red Bluff, CA)	(530) 529-7380

Pacific Gas and Electric Company

Dan Kogut (Manton, CA)	(530) 347-7563
Chip Stalica (Manton, CA)	(530) 347-7559

BATTLE CREEK SALMON AND STEELHEAD RESTORATION PROJECT
SEDIMENT IMPACT ANALYSIS OF THE REMOVAL OF COLEMAN, SOUTH, WILDCAT DIVERSION DAMS ON SOUTH AND NORTH FORK BATTLE CREEKS

Table of Contents

I. INTRODUCTION

Removing Wildcat Diversion Dam, South Diversion Dam and Coleman Diversion Dam will release sediment presently stored behind the dams. The diversion locations are approximately shown in Figure 1. It is necessary to quantify the impacts associated with this sediment release and design appropriate mitigation measures.

There are several different regions within Battle Creek. The region upstream of South Diversion Dam is quite steep with a slope greater than 0.03 (See Table 1 and Figure 2). Therefore, it is able to transport large material and has a large average bed material size, d_{50} ~ 200 mm. Between South Diversion and Inskip Diversion Dams, the slope gradually decreases and the average bed material size decreases slightly. Near Inskip the d_{50} is approximately 100 mm. Downstream of Inskip the slope continues to decrease and then the stream enters a relatively steep canyon where the slope increases again. Near Coleman the canyon opens up and the slope flattens somewhat, such that the slope near Coleman Diversion is similar to that at Inskip (0.012). Because of the similar slope, the measured d_{50} was 100 mm. Downstream of the county bridge to the Confluence with North Fork Battle Creek, the stream enters a canyon and the slope increases again. After the confluence with the North Fork, the slope decreases to less than 0.01, but because of the large flow contribution of the North Fork, the carrying capacity of the stream is not decreased. After the confluence, the stream travels through several miles of canyon, until it opens up just upstream of Coleman Power House. From the Jelly's Ferry Bridge until the confluence with the Sacramento River, the slope is significantly decreased (0.0015) and the bed material becomes significantly finer.

Throughout most of its length, Battle Creek is characterized by alternating pool and riffles that repeat every 5-7 channel widths. The pools are deeper, slower moving reaches of river with finer bed material. The riffles are shallow, swiftly moving stretches of river with relatively coarser bed material. Periodic bars exist along the river bends and store significant amounts of sediment. During high flows these bars are under water and available for transport.

The river has a large range of sediment sizes available for transport. The sizes range from fine sand (0.06 mm) to larger boulders (1 m) with the largest portion of material in the gravel and cobble ranges. There is very little silt or clay present in the bed, until near the confluence with the Sacramento River. Throughout the river, many bars contain a significant amount of sediment. These provide a reservoir of stored sediment that the river can access at high flows.

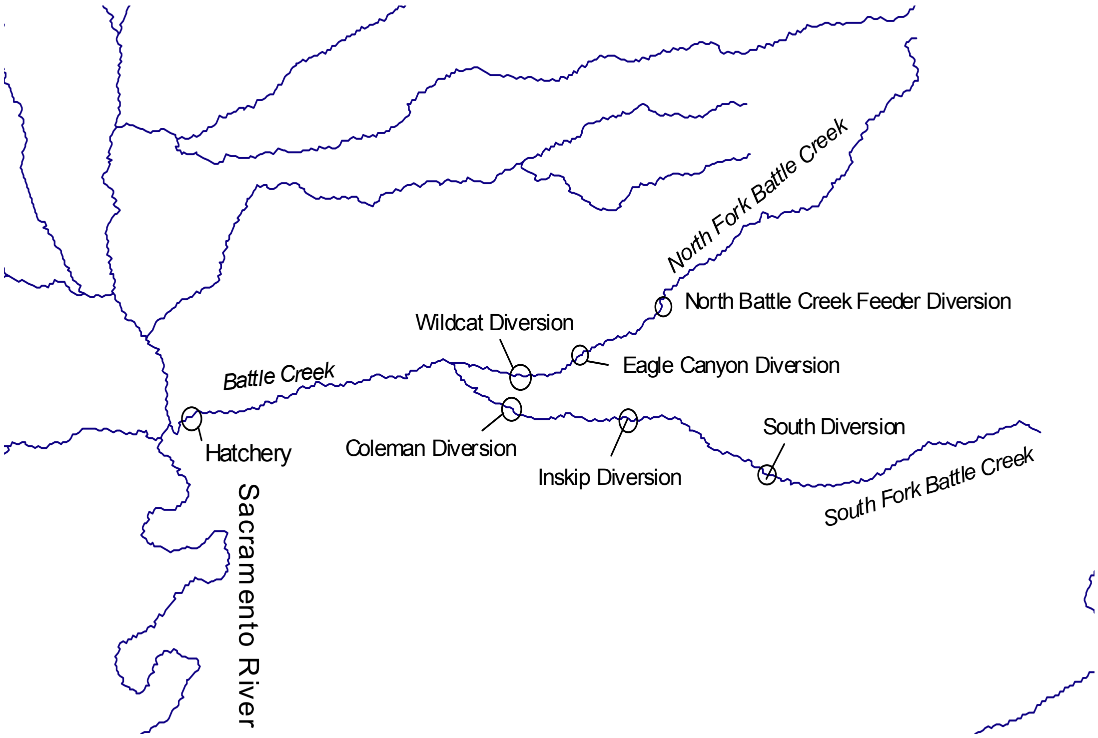


Figure 1. Map showing approximate location of diversion dams.

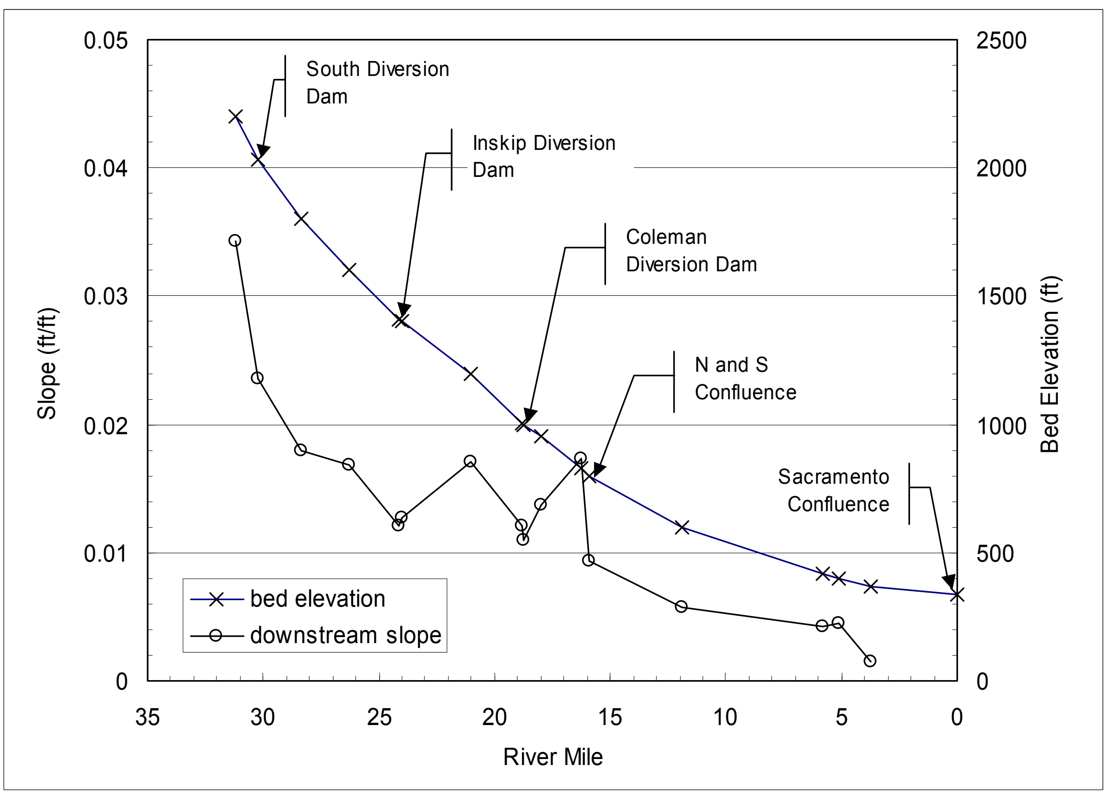


Figure 2. Bed profile of South Battle and Battle Creeks.

Table 1. Location and elevation of select landmarks.

Landmark	**Elevation (ft)**	**River Mile (miles)**	**Downstream Slope (ft/ft)**
	2200	31.18	0.0343
South Diversion Dam	2030	30.24	0.0236
	1800	28.39	0.0180
	1600	26.28	0.0168
Inskip Diversion Dam	1411	24.14	0.0121
	1400	23.98	0.0127
	1200	21.00	0.0171
Coleman Diversion Dam	1002	18.80	0.0121
	1000	18.77	0.0110
Bridge	955	17.99	0.0137
Confluence of N and S Forks	830	16.26	0.0173
	800	15.93	0.0094
	600	11.89	0.0058
Weir at Coleman Hatchery	415	5.82	0.0042
	400	5.14	0.0044
Jelly Ferry's Bridge	368	3.76	0.0015
Confluence with Sacramento River	337	0.00	

II. POTENTIAL IMPACTS

The potential impacts are divided into two categories: general impacts on the river system and local impacts at specific structures.

A. Impacts on river

The removal of the dam could affect these general stream characteristics:

1. Bed Material

Release of sediment downstream has the potential of changing the bed material size in the stream bed. On average, the material trapped behind the dams is finer than that found in the streambed. Therefore, fines may deposit in some areas after dam removal.

2. Sediment Load

The release of trapped sediment will increase the sediment load. Increased sediment load can affect the water turbidity when significant fines are present. The increased sediment load can also cause changes in the bed profile or stream characteristics.

3. Stream Hydraulics

Deposition and changes in the sediment load can cause changes in the bed profile and general stream characteristics. This in turn can change the stream hydraulics, such as changing the stream velocities and depths.

B. Impacts on Specific Structures

The following structures and facilities could potentially be impacted by the release of sediment because of the removal of the diversion dams. Each structure is listed along with the potential impacts at that site. River miles (RM) are the distance along the river to the confluence of Battle Creek and the Sacramento River.

1. Bridge on South Fork Battle Creek immediately upstream of N. and S. Fork Confluence (RM 18): increases in flood water surface elevation due to deposition.

2. Diversion dam immediately downstream of Coleman Powerhouse, called Intake #3 (RM 7.2): increases in deposition rate.

3. Barrier Weir at the Coleman National Fish Hatchery (RM 5.8): Increases in turbidity and sediment load on water treatment plant.

4. Fish Passage at the diversion dam sites.

5. Inskip Diversion Dam (RM 24.1): increases in deposition rate.

III. METHODS

To quantify the impacts listed above, data collection and analysis activities were performed.

A. Data Collection

1. Sediment Bed Material Sampling

On October 4-6, 1999, bed material samples were collected at several locations from South Diversion Dam to the confluence of Battle Creek with the Sacramento River. This included sampling of the sediment behind South Diversion Dam and Coleman Diversion Dam. Because the bed material was large, it was not feasible to remove representative samples from the site. Instead, a combination of the pebble counting procedure, area sampling, visual methods, and bag sampling methods were used. These methods and many others are reviewed in Bunte and Abt (1999). In the pebble counting procedure, several cross sections are selected and the sampler walks these cross sections randomly selecting stones. They are then measured and weighed. At each site, it is recommended that 100 stones be sampled. Area sampling entails marking off a particular sized area and recording every rock that is exposed to the flow. Visual methods included simply recording the general characterization of the bed material at a given site as well as taking a picture of a particular area with a scale included in the photo. Analyzing the photo for particle sizes gives an approximate size gradation at that site. It was recognized that the sediment material below the surface was generally much finer. Therefore, it was possible to collect representative bag samples in the subsurface layer.

Table A1 contains a description of the samples taken along Battle Creek and the results from these samples are in Table A2. The gradation results obtained from the samples listed in Table A1 were combined to obtain gradations that represented the respective area (Figure 3 and Figure 4). The bed material contains a large range of sediment sizes, with the bed material at South Diversion generally larger than that at Coleman Diversion. Near South Diversion, the bed material ranged between boulders near 1 m (1000 mm) in diameter to fine sand. Near Coleman Diversion, the bed material ranged from 0.5 m (500 mm) boulders to silt sized particles.

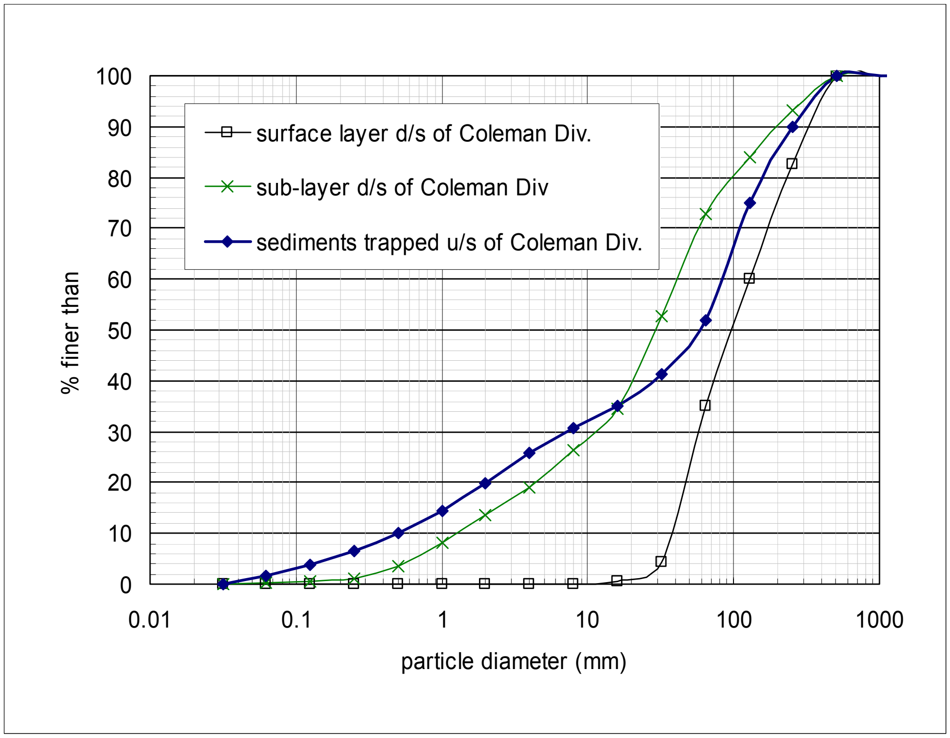


Figure 3. Sediment size gradations near Coleman Diversion Dam.

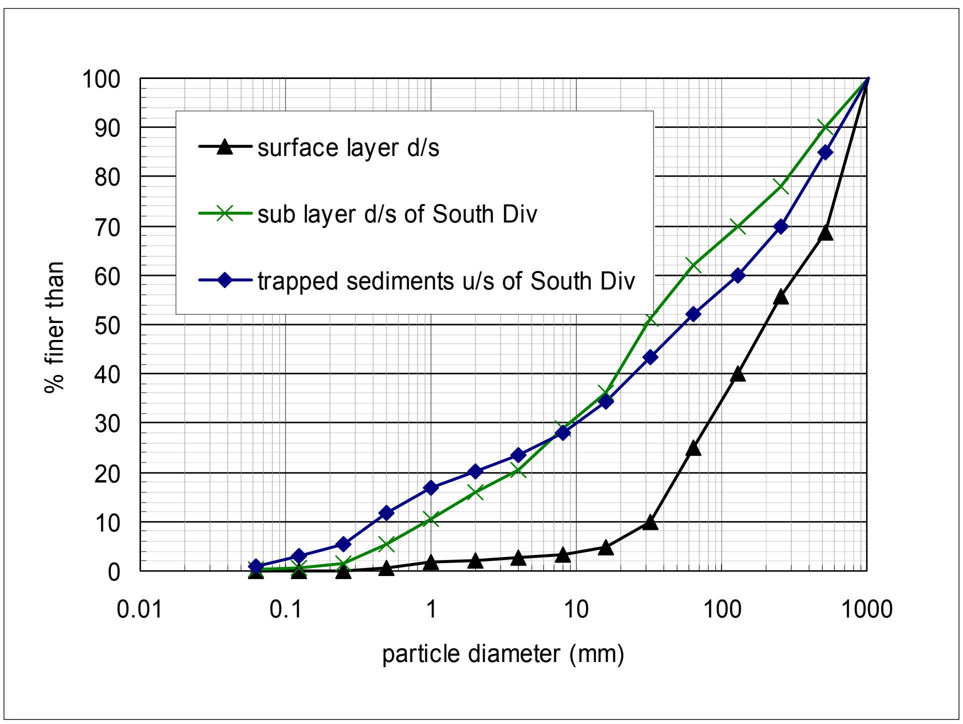


Figure 4. Sediment size gradations near South Diversion Dam

On August 23, 2000, 23 surface samples of the sediment trapped behind Wildcat Diversion Dam were collected and analyzed for size. Averaging of the results gave a composition of 2% silts, 70% sand, and 28 % gravel. Large boulders were also present behind the dam, but many of these had their origin from surrounding cliffs. The full gradation analysis is given in Tables A3 and A4 of Appendix A.

2. Topographic surveys of sediment trapped behind dam

Topographic surveys were conducted of the sediment trapped upstream of South, Coleman, and Wildcat Diversion Dams. The topographic maps of the areas surrounding the dams are included in Appendix B. Using the survey information, the volume of trapped sediment can be estimated if a pre-dam channel is assumed. Assuming a trapezoidal channel with an average width equal to the current channel width, the volumes of trapped sediment are found in Table 2.

Table 2. Volume and depth of sediment trapped behind dams scheduled for removal.

	Wildcat Diversion	**South Diversion**	**Coleman Diversion**
Trapped sediment Volume (yd^3)	5,000	30,000	28,000
Maximum depth of Sediment (ft)	10	23	13

The height of the sediment behind South Diversion dam is large because there has been little dredging at South Diversion Dam resulting in the sediment depositing to an elevation significantly greater than the dam crest.

3. Cross section surveys

To describe the stream geometry, 27 cross sections were surveyed at selected locations from South Diversion Dam to the confluence with the Sacramento River. At most locations, a cross section was surveyed in the pool region and in the riffle region.

B. Analysis

A numerical model of water surface elevations and sediment transport was used to study the sediment impacts on the river system resulting from dam removal. The survey data of the channel geometry and bed material sampling provided the necessary input to the model. The output from the model included streambed elevations, sediment size gradations, and water surface elevations as a function of time after dam removal. The model contains a water routing component and a sediment routing component. The water routing component solves the steady one-dimensional flow equations. The sediment routing component solves the sediment routing equation ignoring changes in suspended concentration or including them, depending upon the user input. It also tracks the changes in bed elevation and bed sorting in a manner similar to GSTARS2.0.

The two dam removal sites were modeled independently. The sediment released during the removal of South Diversion will not cause a significant impact at Coleman Diversion. There are two main reasons for this: 1) Over 11 river miles exist between South Diversion and Coleman Diversion, and Inskip Diversion Dam will remain in place. Therefore, the increased coarse sediment load will be trapped behind Inskip Diversion. 2) Even though small diameter sediment such as fine sands, silts and clays will pass through Inskip Diversion, it will be diluted in its transport over 11 miles.

To perform simulations, many types of input data were required. First representative stream flows were obtained. From previous analysis by DWR, water year (WY) 1983 was considered a typical wet year, WY 1989 was a typical normal year and WY 1977 was considered a dry year (Table 3).

Table 3. Statistics of water years used for sediment computations. Data is at the stream gage located at the Coleman National Fish Hatchery.

Statistic	Wet (WY 1983)	Normal (WY 1989)	Dry (WY 1977)
Minimum Average Daily flow (cfs)	308	187	180
Mean Average Daily flow (cfs)	834	440	236
Maximum Average Daily flow (cfs)	6390	4620	524

The flow splits given in Table 7 in the report titled "Hydrology of North and South Fork Battle Creek" were used to determine the flow in the South Fork Battle Creek. This flow data provided the hydrological input to the model. Sediment bed gradations were obtained from the sediment samples collected in October 1999 (Table A2). The cross section data were obtained from topographic surveys of the reservoir region and the cross section surveys performed throughout Battle Creek. The survey points near the dam were tightly spaced. Along the length of Battle Creek, the cross sections were not taken with a close spacing, but were taken to provide good estimates of the typical channel throughout South Fork Battle Creek. The transport equations of Yang (1973, 1984) were used to determine the sediment transport capacity. There has been no collection of sediment load data and therefore the accuracy of the sediment transport relation cannot be validated.

The sediment transport equation and the measured bed material were used to calculate the upstream boundary condition. The time step used was 2 hours for Coleman Diversion simulations and 1.5 hours for South Diversion simulations. The Manning's roughness coefficient was set to 0.04 for Coleman Diversion simulations and 0.0475 for South Diversion simulations.

IV. RESULTS

The results from the analysis for each of the dams scheduled for removal are presented separately.

A. Wildcat Diversion Dam

The amount of material stored behind Wildcat Diversion Dam is estimated to be 5000 yd^3. Because the amount of material behind Wildcat Diversion Dam is relatively small, there will only be minor impacts from releasing sediment from behind the dam. A simple analysis can be used to estimate the magnitude of the impacts. If the sediment behind the dam were evenly distributed for 1 mile downstream, it would be approximately 4 inches deep. Because the channel is largely contained within steep canyons, small changes in the bed elevations do not significantly impact the river hydraulics. There is some fine material behind the dam, but only approximately 2 percent of the material is silt size or smaller. Therefore, the impacts associated with its release will be small. As a coarse estimate of the expected concentrations of fine material, it is assumed that all the silts behind the dam are released within one day during a flow of 200 cfs. The resulting concentrations of silt would average 414 mg/l for that day. To limit the effect of the high concentrations of fine material, the removal of Coleman Diversion Dam and Wildcat Diversion Dam should be separated by at least 2 days. If the removals are scheduled at the same time, high concentrations of fine material may exist in both the North and South Forks simultaneously. If the removals are separated, then the clean water from the other fork will dilute the high concentrations coming from the fork with the dam removal.

There are many large boulders present behind the dam and because fish passage is of critical concern, some reworking of the boulders may be necessary to ensure fish passage. However, because access to the site is difficult, it may not be feasible to get the proper equipment to the site. It is suggested that after the dam is removed, the site is inspected to ascertain the ability of fish to pass the site. The necessary actions can then be implemented.

B. Coleman Diversion Dam

Based on the analytical analysis and the numerical modeling results, the impacts resulting from the sediment release during Coleman Diversion Dam removal are listed below.

1. General stream characteristics: bed material, sediment load, and stream hydraulics

To understand the effects of the sediment release, it is important to notice that the very coarse sediment load is capacity limited and the very fine sediment load is supply limited. The exact cutoff between being supply limited and capacity limited depends upon the specific flow rate and reach being analyzed. If the sediment size is capacity limited, then introducing more sediment of that size into the system is not going to change the sediment load because the river is already carrying as much as it can. However, if the sediment size is supply limited, introducing more sediment of that size will increase the sediment load accordingly. Based on the surface bed material size (Figure 3), sediment smaller than 10 mm is carried in the flow and not deposited on the bed. This would indicate the sediment smaller than 10 mm is generally supply limited meaning that the stream could transport more than it presently is. However, material larger than 100 mm is capacity limited, meaning that the stream could not transport any more even if more is introduced into the system. Material between these two ranges can be supply limited or capacity limited depending on the particular flow regime.

The amount of sediment being transported on an annual basis can be estimated by first computing a flow duration curve (Figure 5), then using Yang's (1973, 1984) sediment transport formula and the measured bed material (Figure 3). The amount of total sediment being transported on average is on the order of 100,000 yd^3. Of this load, approximately 8,000 yd^3 is gravel size or larger (greater than 2 mm in diameter). Therefore, the material located behind Coleman diversion dam is approximately 28% of the total annual volume and 250% of the annual gravel and cobble volume.

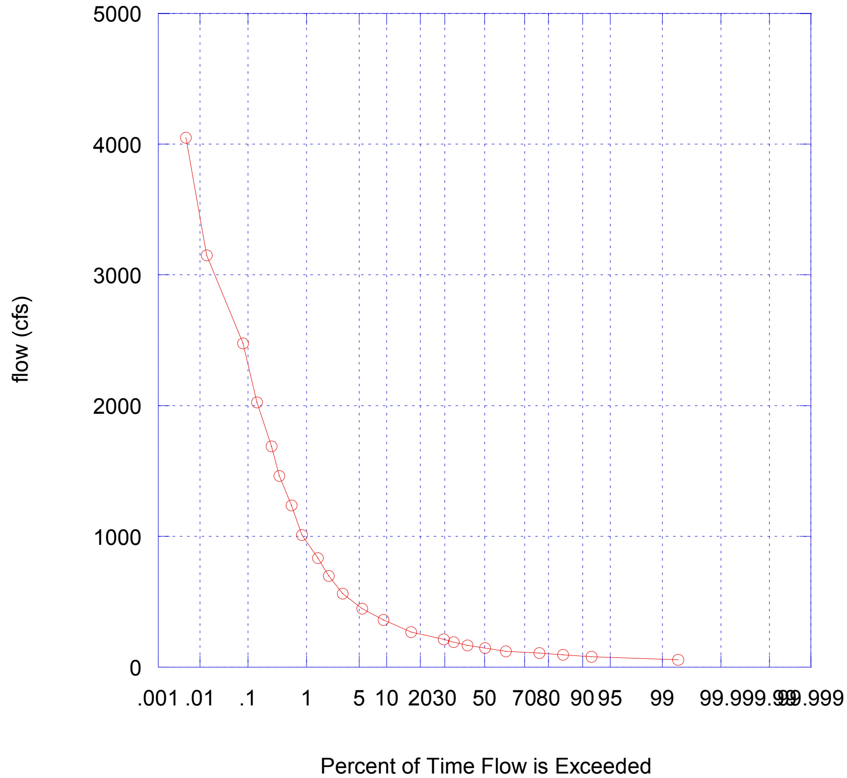


Figure 5. Flow duration curve for South Fork Battle Creek at Coleman Diversion Dam, based on average daily flows for the period of record from 1940 to 1988.

Aerial photographs reveal the large volume of material stored in bars. During high flows, the stream inundates this material and can transport it downstream. Figure 6 is a photograph approximately 1 mile downstream of Coleman Diversion Dam. Notice the gravel bars along the stream. Because there is already a large supply of sediment available to the system, the dam removal is just introducing an incremental additional amount. To quantify the amount of material stored in bars the approximate plan area of the bars was measured from aerial photographs. The depth of each bar was assumed to be 3 feet. From the analysis, it was determined that approximately 5,000 yd^3 of sediment per mile of stream is stored in bars downstream of Coleman Diversion Dam. This translates into 8 miles of stream storing an equal amount of sediment in bars as is trapped behind Coleman Diversion Dam.

Figure 6. Aerial view downstream of Coleman Diversion Dam.

Sluicing is performed on a daily basis during the winter months at Coleman Diversion Dam. Based on visual observation, up to 10,000 yd^3 of material is sluiced during the winter months. This is 36 % of the amount trapped behind Coleman Diversion Dam. No adverse impacts from the sluicing have been reported by downstream water users or people along the creek.

The erosion of material from behind the dam after removal was calculated based on the simulated changes in cross section geometry for each year (Table 4). One can see that for a wet or normal water year, most of the material is eroded in the first year. The amount of material estimated to be moved downstream is less than that estimated to be trapped behind the dam because the estimate was based on an assumed bed profile that was extrapolated from the bed below the dam. The model predicts that the bed elevation immediately below the dam will increase following dam removal and, therefore, the final bed profile is somewhat higher than that assumed by extrapolating the profile from the bed downstream of the dam.

Table 4. Cumulative amount of material eroded from behind Coleman Diversion Dam. Time is relative to dam removal.

	Cumulative Material Removed (yd^3)		
Year	**Wet Years**	**Normal Years**	**Dry Years**
1	12800	9700	2800
2	13100	12500	3000
3	13100	12800	3100
4	13100	12800	3200
5	13100	12800	3500
6	13100	12800	3800

During dry years, much less material is moved downstream. However, because the current sediment transport model does not simulate head cut processes accurately the amount of material during low flows is likely under-predicted. Therefore, the estimate of material removed during the dry year should be considered a lower bound. Nonetheless, it is expected that an equilibrium channel will not be obtained until a few normal water years occur or one wet year. This equilibrium channel is approximately the pre-dam bed profile. In the report entitled "Hydrology of North and South Fork Battle Creek," the equilibrium bed profile is slightly lower. The bed profile was computed by adjusting parameters so that the erosion from behind the dam was maximized as mentioned in Section V of the report.

The bed change in the bed profile is shown in Figure 7, Figure 8, and Figure 9. As is the case with the volume of material behind the dam, the largest changes occur within the first year and less change occurs with each successive year until the channel reaches equilibrium.

Because the sediments stored behind the dam are generally finer than the surface bed of the creek, the sediment release has the potential to alter the gradations of the bed. The numerical model was used to simulate the sediment bed gradations downstream of the dam. To characterize the bed gradations, two representative particle diameters were calculated: d_{35} and d_{50}. This is the particle diameter that 35 % and 50 % of the bed material is finer than, respectively. These were calculated for each cross section and for each time step. The values were then averaged over the cross sections in the one-mile reach below Coleman Diversion Dam. It was found that the average bed material size as measured by the d_{35} and d_{50} did not change more than 20 percent from its original value during any of the simulations. Therefore, it is expected that the dam removal will not have a significant impact on the bed gradation over long reaches of river. There may be some local impacts as the fine material released from the dam moves down the channel. However, the impacts on bed gradation are expected to be temporary and to occur in localized areas.

As mentioned previously, Battle Creek has a pool-riffle structure. The release of sediment has the potential to destroy some of this habitat by the sediment material behind the dam depositing in the pools. The relative volume of the pools was calculated by using the cross section data collected in pool-riffle sequences and supplementing that with the aerial photographs. It was found that the volume of pools is approximately 20,000 yd^3 per mile. As a worst-case scenario, the release of sediment would fill in all the pools for about 1.4 miles below Coleman Diversion

Dam. However, the expected impact is much less and is expected to be temporary. Previous field studies of sediment release in similar streams indicate that the fine material will be deposited in the upstream pools first, then gradually be transported downstream. Each large flow event will scour the fine material out from the pool and deposit it in downstream reaches. At each successive pool downstream, the maximum amount of deposition becomes less (Wohl and Cenderelli, 2000). Eventually, the stream returns to normal conditions. The simulation results showed that the average bed-material size was not significantly affected by the dam removal. This is partly due to the small volume and partly due to the fact that the material behind the dam is of similar composition as the bed. Because pool-riffle geometry is generally not predicted well in 1-D models, specific predictions of the filling and scouring of pools were not obtained. However, the overall bed profile was simulated (Figure 7, Figure 8, and Figure 9). There was no long-term deposition of material within the reach and the bed elevation downstream of the dam remained relatively stable. Therefore, it is expected that the material released from the dam will not deposit for long periods (greater than one year) in pools downstream of the dam. In addition, because the material behind the dam is of similar composition to that already in the bed, its deposition may not affect the downstream bed material significantly.

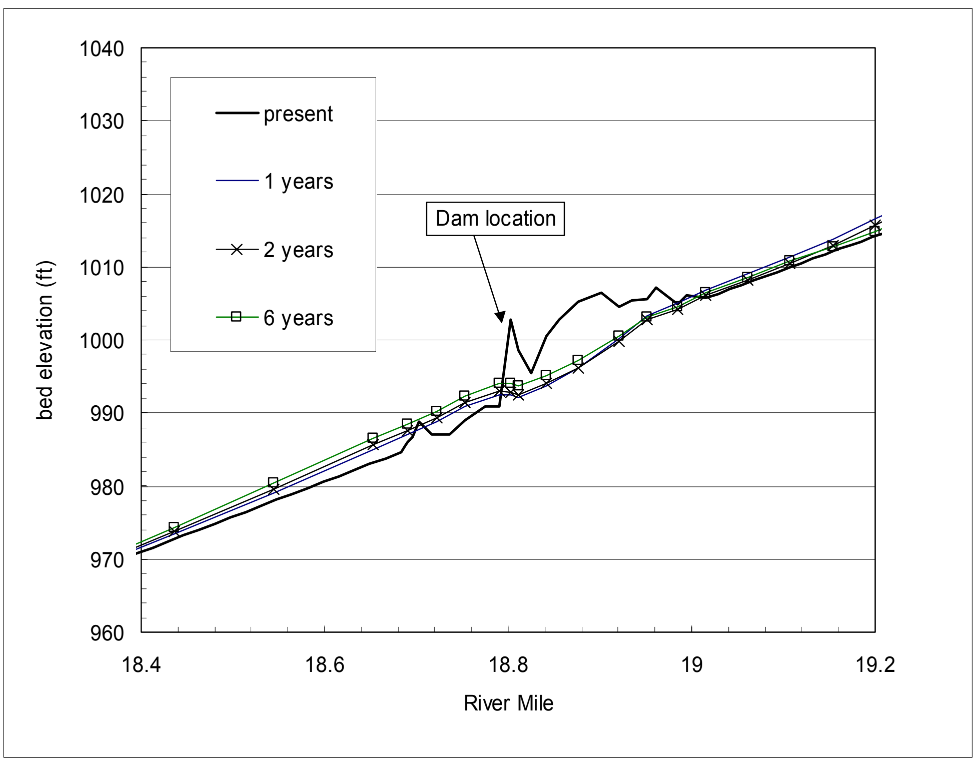


Figure 7. Bed profile near Coleman Diversion Dam following dam removal during wet years.

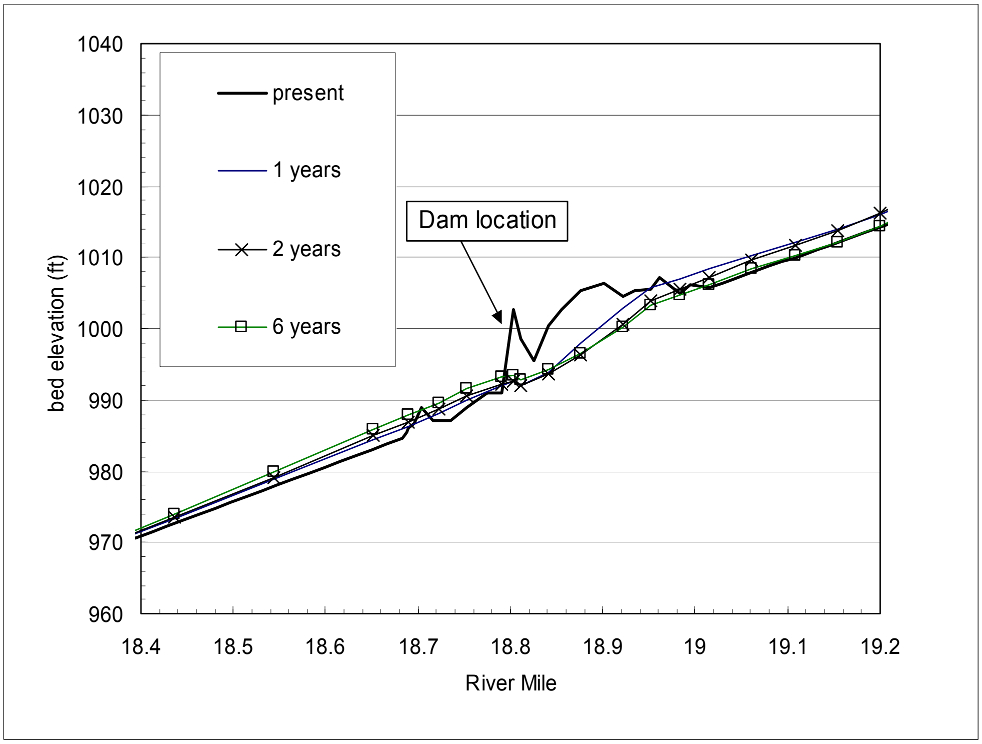


Figure 8. Bed profile near Coleman Diversion Dam following dam removal during normal years.

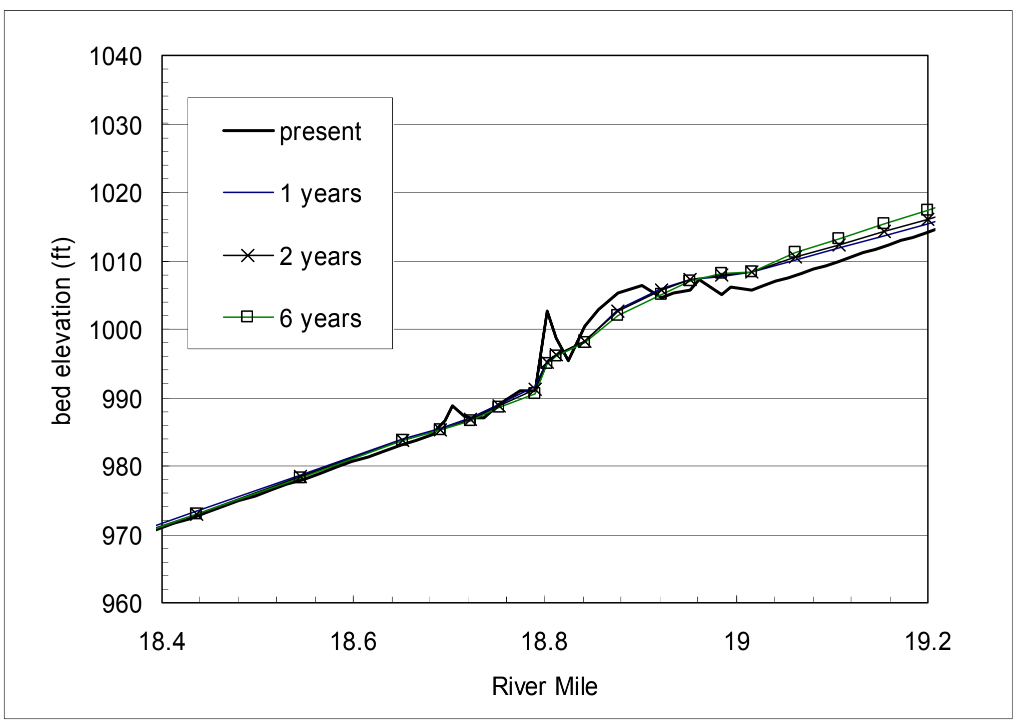


Figure 9. Bed profile near Coleman Diversion Dam following dam removal during dry years.

2. Specific Structures

a. County Bridge on S. Fork Battle Creek immediately upstream of N. and S. Fork Confluence

The release of sediment has the potential to cause deposition at the County Road Bridge. The bridge is located approximately 0.8 miles downstream of the dam. Because the riverbed is mobile, it is scoured during each large event and the subsequent low flow periods refill the scoured regions. Therefore, there is natural variation of the riverbed. The expected change in riverbed elevation due to the removal of Coleman Diversion Dam is shown in Figure 10 for the wet year hydrology.

The simulation showed slight degradation (less than 1 foot over 6 years) near the bridge during the years following removal. Because of the uncertainties inherent in the model, 1 foot over a period of six years is not considered significant and the bed should be considered stable in the reach near the bridge. Therefore, no significant impact will occur on the hydraulics near County Bridge. Figure 10 is for the wet water year simulation, but the other simulations also gave similar results. In particular, for both the normal and dry year simulations the magnitude of bed elevation change was less near the bridge.

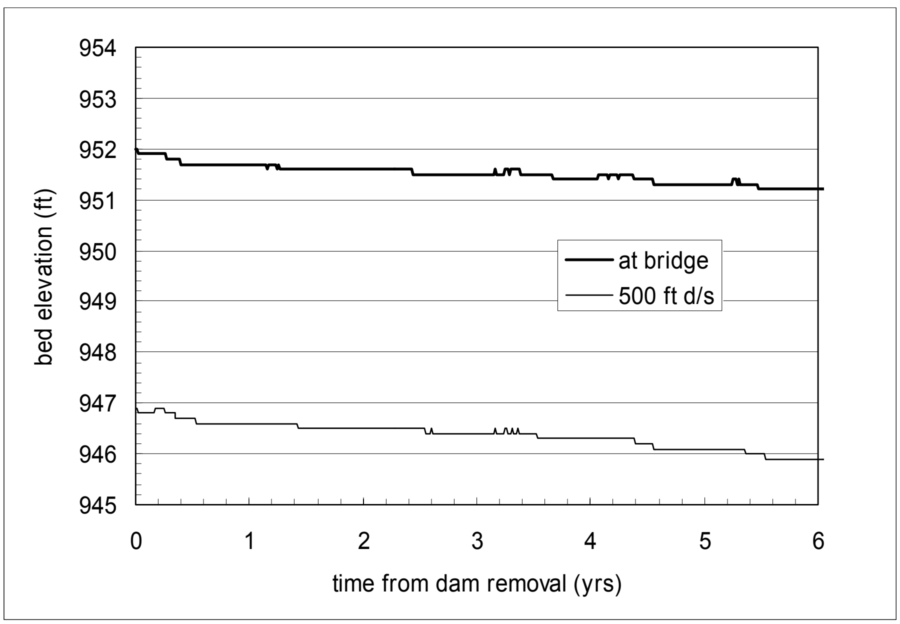


Figure 10. Bed elevation near bridge following dam removal during wet year.

b. Diversion dam immediately downstream of Coleman Powerhouse, called Intake #3 (RM 7.2): increases in deposition rate

The rate of increased deposition at the Coleman Powerhouse is not expected to be significant. Coleman Diversion Dam is located at RM 18.8, 11.6 miles upstream of the Coleman Powerhouse. Based on aerial photography of the river, there is considerable storage of coarse sediment in the form of gravel bars. This provides a continual source of coarse sediment and introducing an incremental amount of more coarse sediment will not significantly affect the total load passing through the system. The only type of sediment load that may be temporarily increased will be the fine material (fine sand and silts). However, if this material deposits in the area upstream of the Coleman Powerhouse, it will likely erode during the next large event.

c. Coleman National Fish Hatchery (river mile 5.8) - Increased turbidity and sediment load increases the load on water treatment plant.

The simulated concentrations of fine sediment (silt size and smaller) in South Fork Battle Creek just upstream of the North Fork and South Fork confluence are shown Figure 11. It was assumed that the flow in South Fork Battle Creek was 350 cfs during the simulation. This would be a relatively high flow during the summer months. There is an immediate rise in the silt concentration following dam removal followed by a gradual decline.

Based on these results, the large rises in turbidity due to dam removal will be confined to days immediately following dam removal and during the first few large events that erode large amounts of sediment. It should be noted that these computations do not include wash load, which is the sediment load that does not arise directly from the bed material. Based on the simulation, the maximum concentration of fine sediment in Battle Creek due to the removal of Coleman Diversion Dam is expected to be near 10,000 mg/l and this high concentration will last several hours (Figure 11). Because the water will be diluted by water from North Fork Battle Creek, which has a very low silt concentration during low flow, the maximum concentration experienced at the Coleman National Fish Hatchery may be approximately one-half of that predicted at the confluence of North and South Fork Battle Creek. Regardless, the Coleman National Fish Hatchery should be notified as to the day of removal so that they can prepare for the temporary increase in turbidity at their plant.

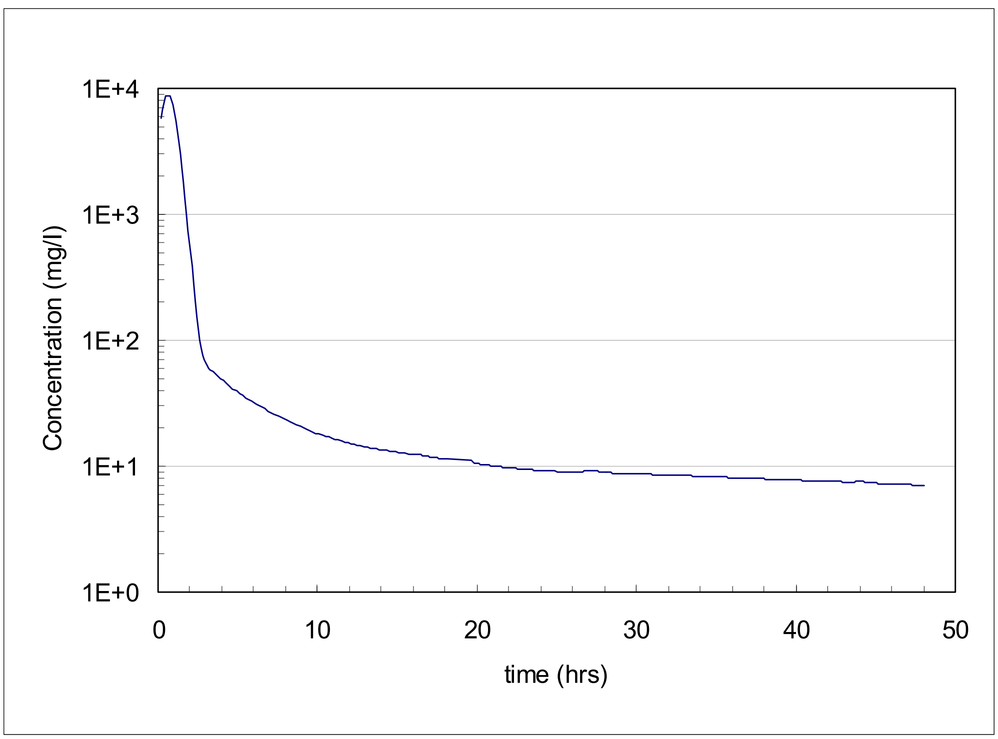


Figure 11. Concentration of fine material in South Fork Battle Creek immediately upstream of North and South Battle Creek following removal of Coleman Diversion Dam.

d. Fish Passage at the diversion dam sites.

A channel will form quickly behind the dam after removal. The bed profile after one-year is shown in Figure 7, Figure 8, and Figure 9. While it may take several months or years for the channel to completely return to pre-dam conditions, the majority of the sediment reworking and initial low flow channel formation will take place during the first spring runoff. Even though erosion is expected to occur relatively quickly, the channel should be monitored so that fish passage is ensured. If some large rapids or boulders block fish passage, some minor reworking of the sediment could be performed to remedy this.

C. South Diversion Dam

Because Inskip Diversion Dam is located below South Diversion Dam, the impacts due to the sediment release at South Diversion will be mainly confined to the reach between them. The only impact that could possibly be felt downstream of Inskip is an increase in silt concentration.

The main sediment related impact on the reach between South Diversion and Inskip Diversion would be increased deposition at Inskip Diversion. However, this increase is expected to be small because of the same reasons the deposition near Coleman Powerhouse is expected to be small due to the removal of Coleman Diversion Dam. A large amount of sediment is stored in gravel bars that can be accessed during high flows and the downstream distance is large (6 miles). Based on aerial photographs, it is estimated that approximately 2,000 yd^3/mile is stored in bars along the river. The upper bound of additional sediment that would be deposited behind Inskip Diversion due to the removal of South Diversion Dam would be all material removed from behind South Diversion Dam. During a wet year, this could be as much as 8,300 yd^3. However, not all the material removed from behind South Diversion will continue onto Inskip Diversion. Much of the material would be stored along the river channel in bars. A better estimate of the additional material that would be deposited behind Inskip is obtained by running the numerical model with the material trapped behind the dam already removed so that the river is at natural conditions. The amount of additional material deposited behind Inskip Diversion Dam due to the removal of South Diversion Dam is then calculated by subtracting the amount deposited behind Inskip Diversion under natural conditions from that calculated following dam removal. The results from this calculation are shown in Table 5. For the wet water years, the largest amount of additional material would be deposited the first year, 800 yd^3, and decrease to zero in the second year. For the dry and normal years, practically no effect will be felt at Inskip Diversion. This is because the flow is capacity limited for these flows, meaning that introducing more sediment does not necessarily increase the sediment transport rate.

Table 5. Cumulative amount of material eroded from behind South Diversion Dam and cumulative additional deposited behind Inskip Diversion. Time is relative to dam removal.

	Cumulative Material Removed (yd^3)			**Cumulative Additional Deposited Behind Inskip Div. (yd^3)**		
Year	**Wet Years**	**Normal Years**	**Dry Years**	**Wet Years**	**Normal Years**	**Dry Years**
1	8300	7600	560	800	0	0
2	14500	12800	580	800	0	0
3	19100	18000	750	800	0	0
4	19100	22000	990	800	0	0
5	19100	22000	1400	800	0	0

	Cumulative Material Removed (yd^3)			Cumulative Additional Deposited Behind Inskip Div. (yd^3)		
Year	Wet Years	Normal Years	Dry Years	Wet Years	Normal Years	Dry Years
6	19100	22000	1400	800	0	0

The bed profiles resulting from the computations are shown in Figure 12, Figure 13, and Figure 14. After the first wet water year the bed profile is similar to the pre-dam conditions. The normal year simulations return slightly more gradually to the pre-dam conditions, but the return is still rapid. For the dry year, little change in the bed profile occurs. However, as mentioned before, the numerical model does not simulate the head cut process well. Even a relatively low flow would have the ability to form a low flow channel through the sediments behind the dam. Therefore, the bed profile for the dry water years would likely be closer to the pre-dam profile than shown in Figure 14.

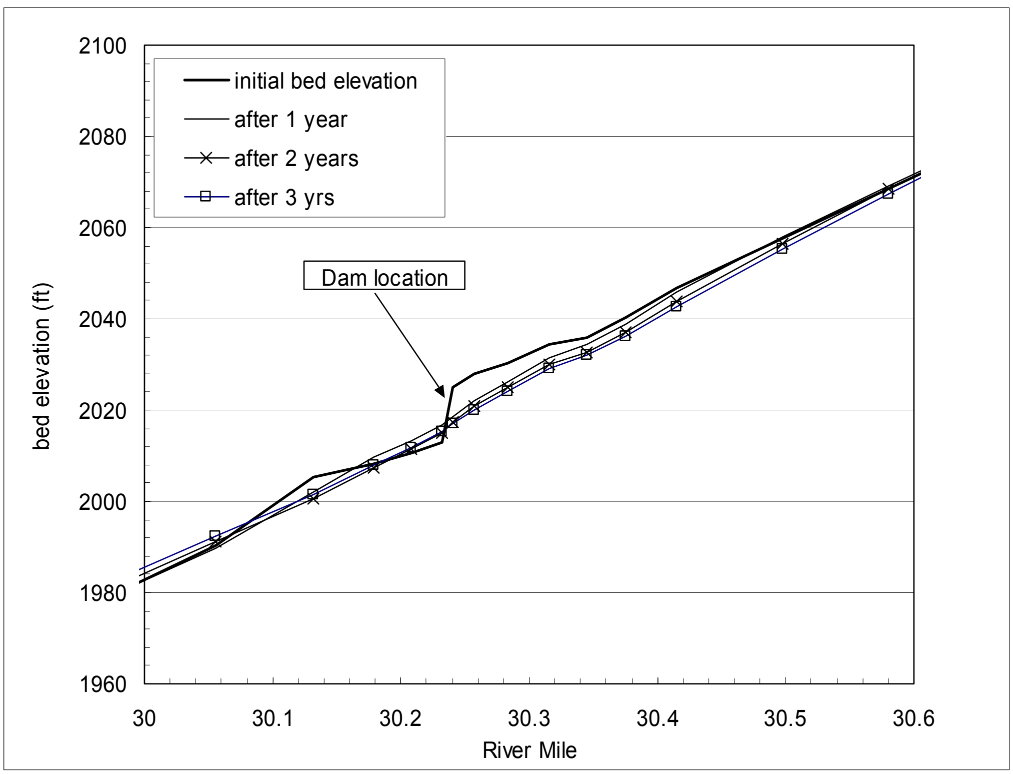


Figure 12. Bed profile near South Diversion Dam following dam removal during wet years.

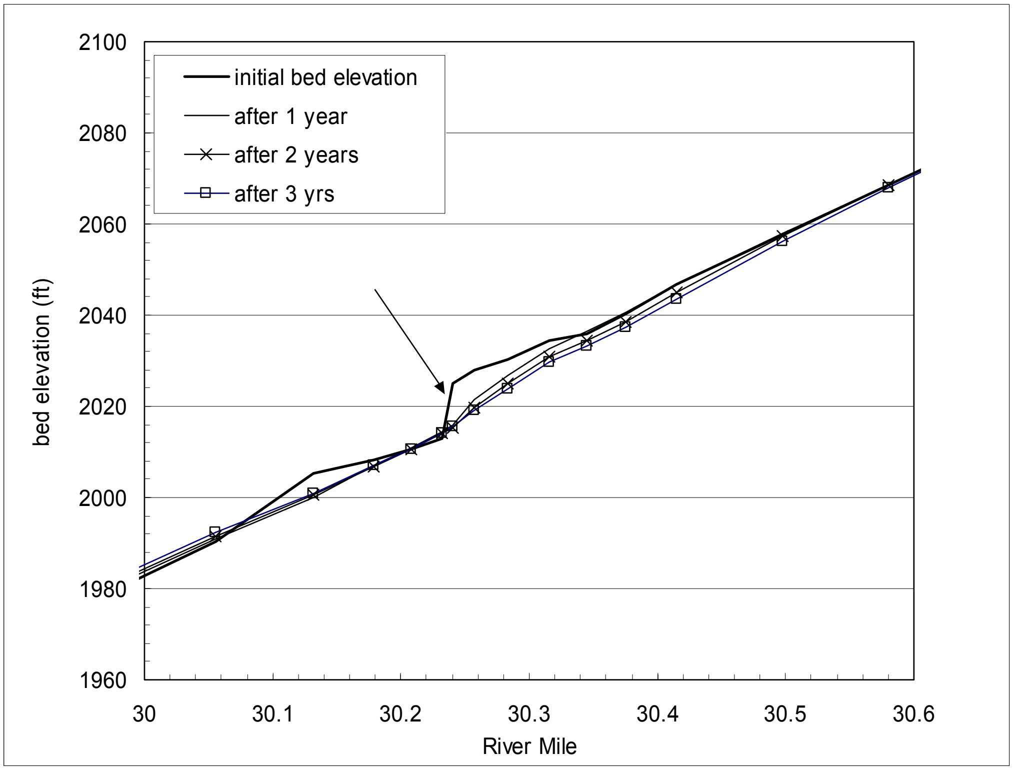


Figure 13. Bed profile near South Diversion Dam following dam removal during normal years.

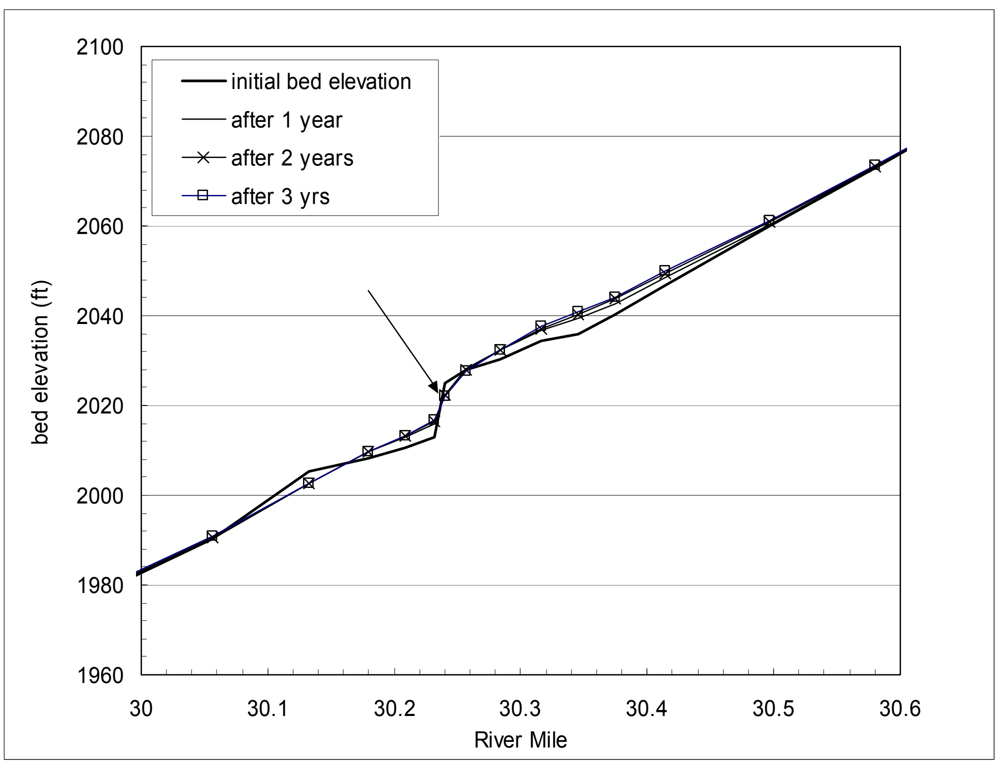


Figure 14. Bed profile near South Diversion Dam following dam removal during dry years.

The pool volume downstream of South Diversion is estimated to be 14,000 yd^3/mile. As a worst-case scenario, the sediment from behind South Diversion would fill pools in a two-mile stretch of river downstream of the dam. However, the material trapped behind the dam is of similar composition to the material in the bed and therefore the release of the sediment will not significantly change the composition of the bed material (see Figure 3 and Figure 4).

IV. SUMMARY

The impacts associated with the sediment release due to the removal of three diversion dams, Wildcat Diversion Dam, Coleman Diversion Dam and South Diversion Dams was analyzed. The estimated amount of sediment trapped behind each dam is found in Table 2. A simple analysis of Wildcat Diversion Dam proved that the impacts would be minimal and therefore, no numerical modeling was performed for Wildcat Diversion Dam. A numerical model was used to simulate the movement of sediment as the result of removing Coleman Diversion Dam and South Diversion Dam. The numerical model was used to analyze the rate at which material was removed from behind the dam and the downstream of effects. Based on the numerical modeling results, the return to near pre-dam conditions should occur within 1 or 2 normal water years. No sediment removal is necessary. However, if a low flow channel is not rapidly formed through the deposits behind the diversion dams, it is recommended that some minor reworking of the sediments be performed so that fish passage is ensured.

V. RECOMMENDATIONS FOR FURTHER WORK AND MONITORING

Once the dam is removed, it would be beneficial to organize a monitoring plan. This monitoring plan would be beneficial in three ways:

1. Monitoring data could be used to improve understanding of sediment impacts following dam removal.

2. Monitoring would provide real time data to assess the need for adaptive management.

3. Monitoring data would provide basis to assess impacts of sediment release.

The monitoring plan should include:

1. Time lapse photography in the reservoir region: A still camera should be installed at each dam site and set to take pictures 4 times a day immediately following removal. After the reservoir region starts to change more slowly, the interval for pictures could be reduced to once a day, then to once a week. The photograph should contain the full width of the reservoir region extending from approximately 100 feet downstream of the dam to approximately 500 feet upstream from the dam. This may require multiple cameras. The photographs will provide important insight into the behavior of the sediment trapped behind the dam. In addition, the cost to install such cameras is small relative to the value that the photographs will have.

2. Perform additional surveys during the dry season preceding dam removal: This will provide a baseline for the changes induced by dam removal. Cross sections should be surveyed every 100 feet for 1 mile downstream of Coleman and South Diversion dams. At these same locations, the surface layer of bed material should be sampled. This can be done either by the pebble count procedure or grab samples. In addition to cross sections immediately downstream of the dams, cross section information should be collected near structures that will potentially affected. These structures are:

   a) Bridge on S. Fork Battle Creek immediately upstream of N. and S. Fork Confluence

(RM 18) - cross sections every 100 feet extending 300 feet downstream to 100 feet upstream.

b) Diversion dam immediately downstream of Coleman Powerhouse (RM 7.2) - every 200 feet extending upstream 1600 feet.

c) Inskip diversion dam (RM 24.1) - every 200 feet extending upstream 1600 feet.

3. Continue monitoring the turbidity and total suspended solids (TSS) downstream of Coleman Diversion at the County Bridge and upstream of the intakes to Coleman National Fish Hatchery. The sampling should be performed as close as possible to the peak flow of each high flow period. At a minimum the sampling should be done monthly.

VII. REFERENCES

Bunte, K., Apt, A., "Sampling Surface and Subsurface Particle-Size Distributions in Gravel-Bed Streams," Engineering Research Center, Colorado State University, 1999.

Wohl, E.D., Cenderelli, D.A., "Sediment Deposition and Transport Patterns Following a Reservoir Sediment Release," Water Resources Research, Vol 36, No. 1, 319-333, 2000.

Yang, C.T. "Unit Stream Powers and Fluvial Hydraulics," J. Hydraulics Division, American Society of Civil Engineers, Vol. 99, No. 10, 1973.

Yang, C.T. "Unit Stream Power Equation for Gravel," J. Hydraulic Engineering, American Society of Engineers, Vol. 110, No. 12, 1984.

Appendix A. Bed Material Samples

Table A1. Description of sediment sampling along Battle Creek.

Description	**Label**
areal sample, surface layer u/s of South Div	ST-B1
sublayer sample of bar	ST-B2
Pebble Count of u/s of South Div	ST-B3
Surface sample of bar d/s of South Div	ST-B4
Surface sample of bar d/s of South Div, lab anal.	ST-B5
sublayer sample beneath ST-B1	ST-S1
bed mat. of sublayer d/s of South Div, lab anal.	ST-S4
bed mat. of sublayer d/s of South Div, lab anal.	ST-S5
bed mat. of sublayer d/s of South Div, lab anal.	ST-S5A
bed mat. of sublayer d/s of South Div, lab anal.	ST-S5B
Pebble Ct d/s of South Div	ST-P2
surface bed mat. at Coleman dam	CB-1,top
sublayer bed mat. at Coleman dam, lab anal.	CB-1, sub
surface bed mat. at Coleman dam-pebble ct	cb-2
surface bed mat. at Coleman dam-pebble ct	C-p1
pebble ct of refuse pile-Coleman	c-p2
pebble ct of refuse pile-Coleman	c-p3
sublayer bed mat. at Coleman dam, lab anal.	cb-2a
sublayer bed mat. at Coleman dam, lab anal.	cb-2b
lab samples of ref. Pile at Col.	C-B3
lab samples of ref. Pile at Col.	cb-4
surface bed mat., at Bridge D/s of Coleman, lab	CB-5
surface Gravel sample at Confluence	B-B1
Pebble Ct. near conf. N./S. Battle	B-P1
surface bed mat. gravel bar near conf. N/S Battle	B-P1
Pebble Ct. near bar at Coleman Power Plant	B-P2
Pebble Ct.at riffle, Coleman Power Plant	B-P3
Pebble Ct.at riffle, d/s of historical br.	B-P4
Sub-layer in pool at Coleman fish hatchery, lab anal.	B-S2
Sub-layer in pool, d/s of historical br., lab anal.	B-S3
Sub-layer, bar , d/s of historical br., lab anal.	B-S4
Sub-layer, stream, d/s of historical br., lab anal.	B-S5
Taken side of streambed, confluence Battle Ck. And Sacramento R.	B-S6

Table A2. Sediment Gradations in South Fork Battle Creek and Battle Creek

	% finer than (mm)																
Label	**2048**	**1024**	**512**	**256**	**128**	**64**	**32**	**16**	**8**	**4**	**2**	**1**	**0.5**	**0.25**	**0.125**	**0.0625**	**0.032**
ST-B1	100	100	45.6	18.7	0												
ST-B2	100	100	100	100	99.6	67	62	58	56	53	49	36	17	9	3		
ST-B3	100	88.5	1.95	0.16	0												
ST-B4	100	100	100	100	99.6	71	35	22	15	10.5	6	3	0.7				
ST-B5	100	100	100	99.4	46	6.5	3	3	3	3	3	3					
ST-S1	100	100	100	100	99.7	78	52	35	22	14	7.5	3.5	1.5	0.6			
ST-S4	100	100	100	100	100	99.6	83	62	43	30	14	6.5	1.5	0.3			
ST-S5	100	100	100	100	99	90.5	88	75	67	61	50	30	9	2.3	0.9		
ST-S5A	100	100	100	100	100	99.5	58	42	25	15	6.5	2.5	0.8				
ST-S5B	100	100	100	100	98.5	80	42	38	18	12	5.5	2	0.55				
ST-P2	100	37.46	11.53	1.9	0.54	0.3	0										
CB-1,top	100	100	100	46.2	6.1	0	0	0	0	0	0	0	0	0	0	0	0
CB-1, sub	100	100	100	100	100	100	100	99.2	90	80	63	52	50	40	25	5	1
cb-2	100	100	100	100	25.5	0.7	0	0	0	0	0	0	0	0	0	0	0
C-p1	100	100	100	70.3	17.8	0.6	0	0	0	0	0	0	0	0	0	0	0
c-p2	100	100	100	13.2	4	0.6	0	0	0	0	0	0	0	0	0	0	0
c-p3	100	100	100	39	10.2	0.4	0	0	0	0	0	0	0	0	0	0	0
cb-2a	100	100	100	100	100	98	8	0.32	0.22	0	0	0	0	0	0	0	0
cb-2b	100	100	100	100	100	99.4	70	50	40	30	20	12	5	1.5	0.6	0	0
C-B3	100	100	100	100	100	99.6	77	65	58	50	42	32	23	16	10	5	0
cb-4	100	100	100	100	100	99.5	70	56	50	40	30	20	12	9	5.5	3	0
CB-5	100	100	100	100	100	96	78	46	33	23	18	12	7	2.7	1.2	0.6	0
B-B1	100	100	100	100	100	99.7	92	68	55	40	27	15	5	1	0.25	0	0
B-P1	100	100	100	65.4	8.5	0.5	0	0	0	0	0	0	0	0	0	0	0
B-P1	100	100	100	100	100	100	8.6	1.2	0	0	0	0	0	0	0	0	0
B-P2	100	100	100	45.7	27.5	2.3	0.2	0	0	0	0	0	0	0	0	0	0
B-P3	100	100	100	27.9	1.4	0.1	0	0	0	0	0	0	0	0	0	0	0
B-P4	100	100	100	92.5	16.7	0.9	0.1	0	0	0	0	0	0	0	0	0	0
B-S2	100	100	100	100	100	99.5	60	33	25	20	17	12	6	1.8	0.16	0	0
B-S3	100	100	100	100	100	100	100	100	100	99.8	99.3	93	50	40	10	3.5	0
B-S4	100	100	100	100	100	99.5	70	36	30	23	18	15	10	4	1.7	0.8	0

B-S5	100	100	100	100	100	99.2	68	40	28	20	15	8	4.5	1.5	0.14	0	0
B-S6	100	100	100	100	100	100	100	100	100	100	99.9	99.75	99.3	92	50	14	3.5

Table A3. Sediment Gradations behind Wildcat Diversion Dam. Samples for gradation analysis collected at five foot intervals across the North Fork of Battle Creek, 20 feet upstream from Wildcat Dam. Sample WC-1 starts at the left creek bank, with increasing sample numbers towards the right bank. From bank to bank the width is 62 feet.

Sample Number	Water Depth (feet)*	Sample Depth (feet)	Fines (%)	Sand (%)	Fine Gravel (%)	Coarse Gravel (%)	Cobbles (%)	Max. Size (feet)	Organics % / color
WC-1	0.0	0.3	55	30	10	-	-	0.25	5 / brown
WC-2	2.8	0.5	20	80	Tr	-	-	2.5	/ brown
WC-3	4.4	0.3	20	80	-	-	-	1.5	/ brown
WC-4	4.1	0.3	10	70	20	-	-	0.15	/ brown
WC-5	3.0	0.3	5	35	40	20	-	0.20	5 / brown
WC-6	2.0	0.3	20	65	10	5	-	0.20	/ brown
WC-7	2.0	0.3	5	20	60	10	-	0.10	/ brown
WC-8	2.0	0.3	5	20	55	20	-	0.10	/ brown
WC-9	2.2	0.5	5	65	30	-	-	0.05	/ brown
WC-10	2.7	0.6	5	90	5	Tr	-	0.08	/ brown
WC-11	2.6	0.5	40	20	10	30	-	0.30	/ brown
WC-12	1.8	0.6	10	70	10	10	-	0.10	/ brown
WC-13	2.2	0.7	60	40	Tr	-	-	0.05	/ brown

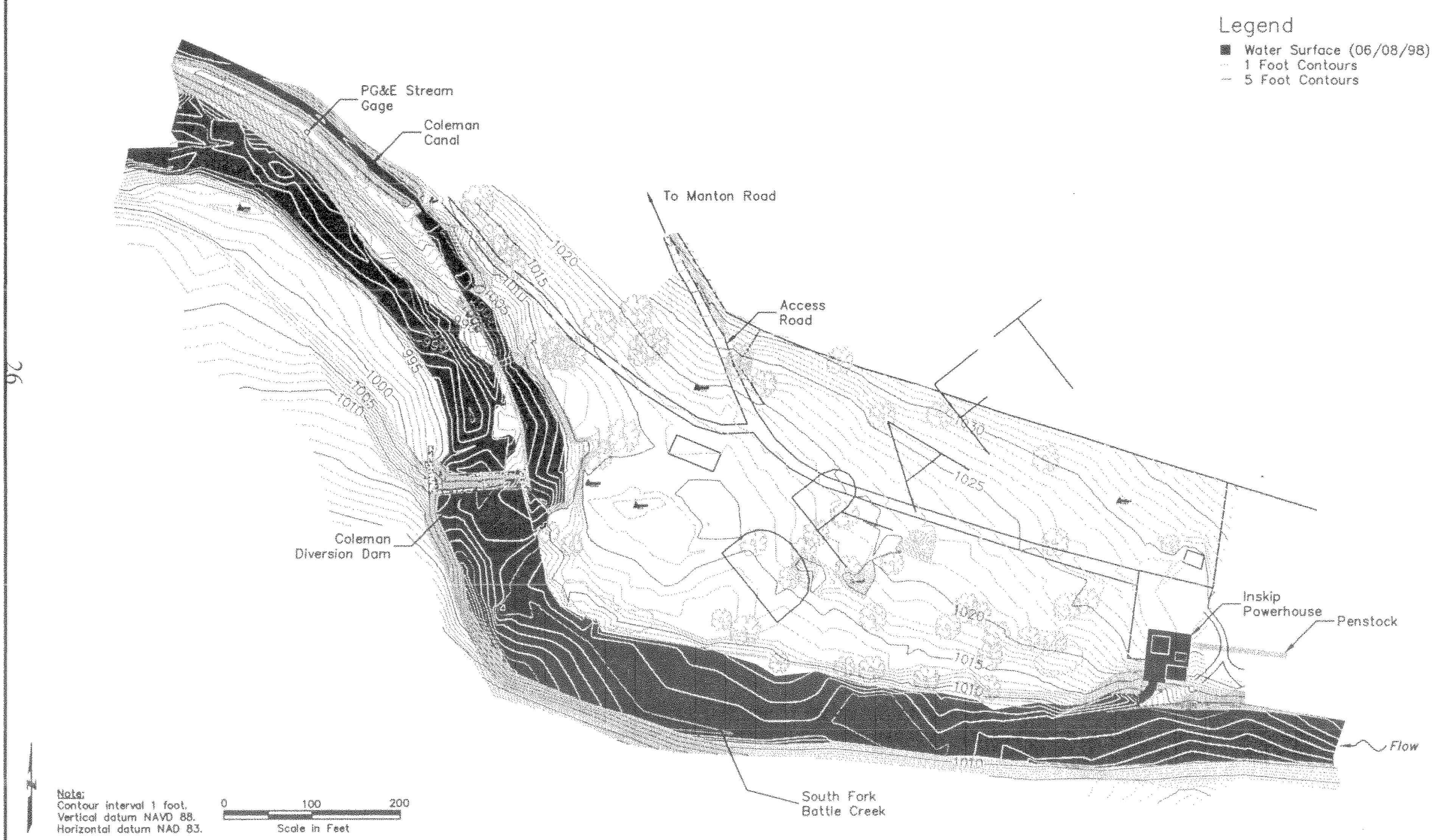
* Approximately 0.3 feet of water was flowing over the dam throughout the sample collection process.

Table A4. Samples for gradation analysis collected at five foot intervals across the North Fork of Battle Creek, 50 feet upstream from Wildcat Dam. Sample WC-14 starts ½ foot in the creed from the left creek bank, with increasing sample numbers towards the right bank, ending with sample WC-23. From bank to bank, the width is 46.5 feet.

Sample Number	Water Depth (feet)*	Sample Depth (feet)	Fines (%)	Sand (%)	Fine Gravel (%)	Coarse Gravel (%)	Cobbles (%)	Max. Size (feet)	Organics % / color
WC-14	1.9	0.5	5	60	35	-	-	0.05	/ brown
WC-15	2.2	0.3	tr	30	50	20	-	0.20	/ brown
WC-16	2.6	0.1	tr	15	15	60	30 (two)	0.40	/ brown
WC-17	2.3	0.4	tr	60	30	10	-	0.25	/ brown
WC-18	2.7	0.3	5	75	20	-	-	0.05	/ brown
WC-19	2.6	0.3	5	50	35	-	-	0.05	/ brown
WC-20	1.8	0.3	5	35	40	20	-	0.20	/ brown
WC-21	0.9	0.5	5	35	50	10	-	0.15	/ brown
WC-22	0.4	0.5	10	85	5	-	-	0.05	/ brown
WC-23	0.3	0.6	35	60	-	-	-	-	5 / brown

* Approximately 0.3 feet of water was flowing over the dam throughout the sample collection process.

Appendix B. Topographic maps near diversions scheduled for removal.



COLEMAN DIVERSION FISH PASSAGE PROJECT
South Fork Battle Creek near Manton, California

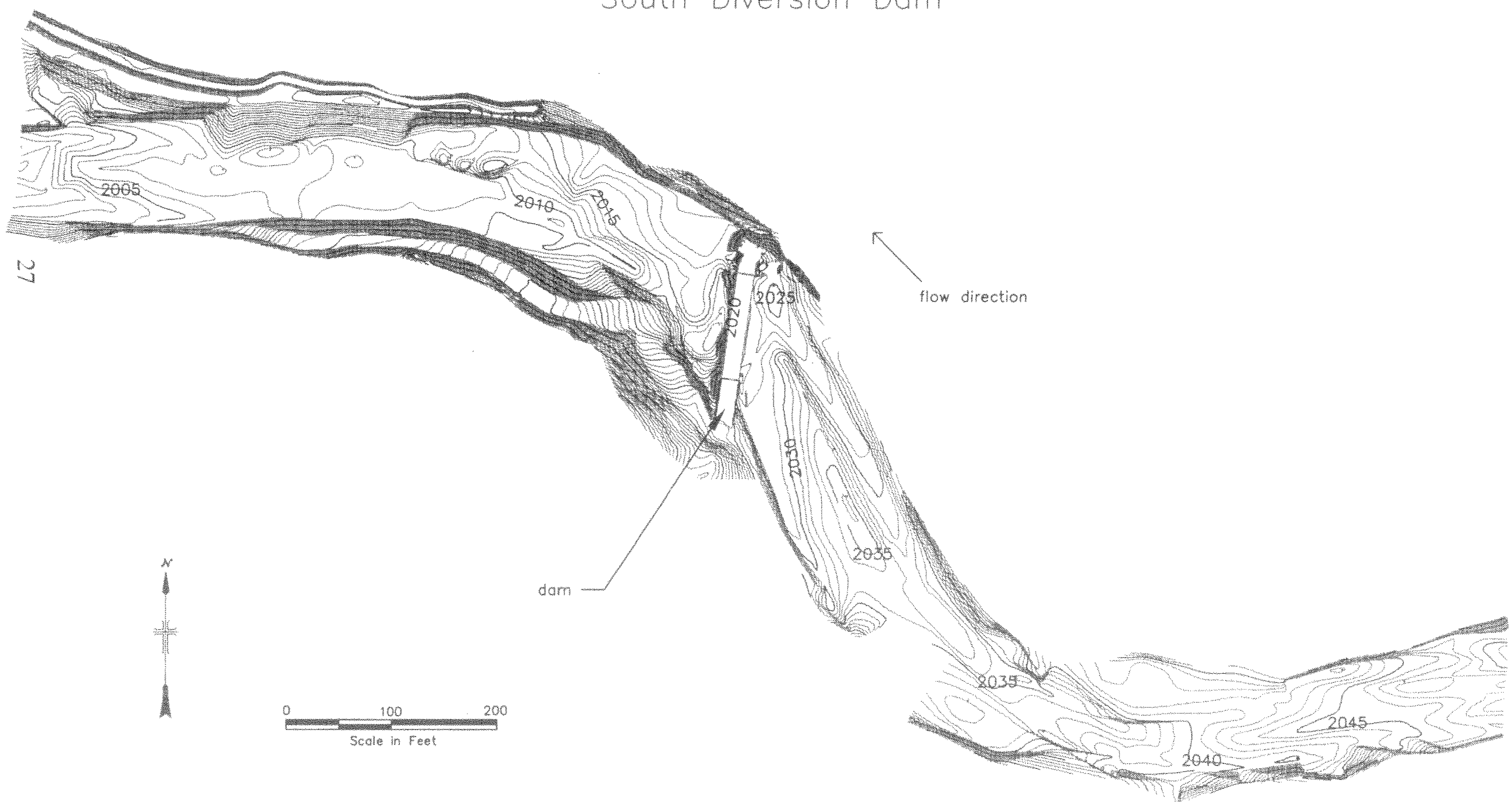
Coleman Diversion Site Plan

DRAWING : Coleman

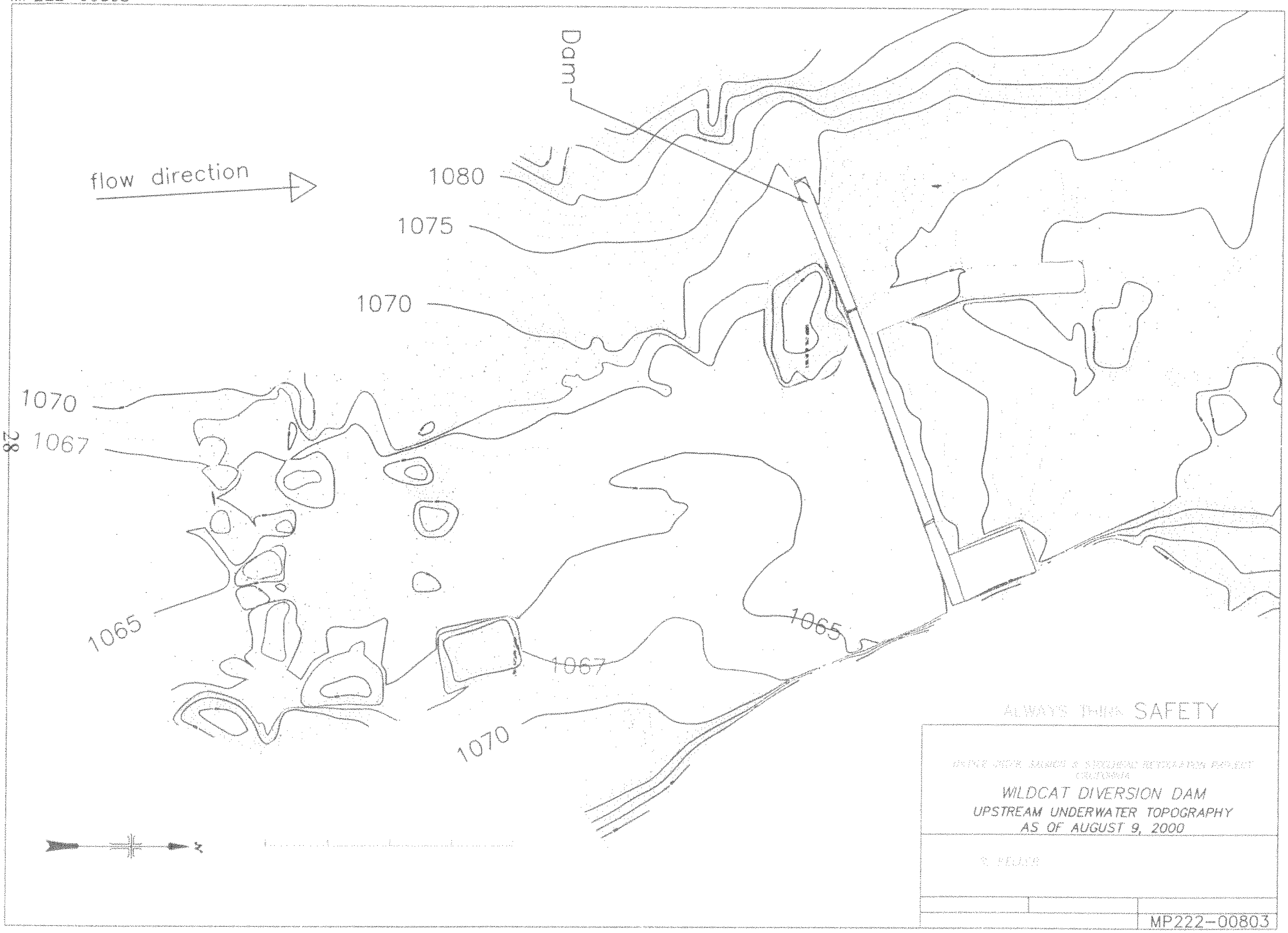
Revision Date: September 30, 1999

Sheet ? of ?

South Diversion Dam



MP222-00803


Dam
flow direction
1080
1075
1070
1070
1067
1065
1065
1067
1070
ALWAYS THINK SAFETY
WILDCAT DIVERSION DAM
UPSTREAM UNDERWATER TOPOGRAPHY
AS OF AUGUST 9, 2000
MP222-00803