Final Report

Evaluation of Sediment Management Options for the Buckman Diversion Project

Prepared for

LAS CAMPANAS
SANTA FE

and City and County
of Santa Fe, New Mexico

March 2003

CH2MHILL

in association with
CDM, Inc.

Final Report

Evaluation of Sediment Management Options for the Buckman Diversion Project

Submitted to

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Acronyms

ac-ft/yr	acre-feet per year
BLM	Bureau of Land Management
cfs	cubic feet per second
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
mgd	million gallons per day
mm	millimeter
mg/L	milligrams per liter
MRC	Municipal Recreation Complex
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
SJC	San Juan-Chama
TSS	total suspended solids
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

Summary of Conclusions

The diversion of Rio Grande water at the proposed Buckman intake site will result in the need to manage considerable quantities of suspended sediment. If not properly managed, this material, particularly that fraction in the sand-sized range of >0.1 millimeter (mm) in diameter, can cause significant engineering and operational problems with pumps and conveyance pipelines.

An evaluation and comparison of five sediment management options was undertaken to identify the best alternative for removal and disposal of the >0.1-mm material.

- A Sand-Return option involved removal (by mechanical separators) and return of > 0.1-mm sized sediments to the river below the Buckman intake.
- Two Storage-Trucking options involved near-river removal, storage, and trucking of material to the Caja del Rio landfill in southwest Santa Fe.
- A Slurry-Line option examined the construction of a separate sediment slurry line to convey sediments to the City/County water treatment plant near the Municipal Recreation Complex (MRC).
- Finally, an All Pumping option evaluated pumping all the sediment in the main conveyance pipeline to the proposed regional water treatment plant.

Criteria used in the assessment of these options included: costs [capital and operation and maintenance (O&M)]; technical/operational feasibility; river water quality; permitting considerations; and quality of life issues including traffic, safety, noise, aesthetics, and air quality. Only the Sand-Return option and Storage-Trucking options were considered feasible. The Sand-Return option was judged to be clearly advantageous and least expensive of the five options evaluated based on these criteria. Moreover, an evaluation of the sand return on the sediment and turbidity concentrations in the Rio Grande indicates virtually no discernable effect on the river.

Background

The Buckman river diversion project (Project), currently in planning by a group (Proponents) comprising the City of Santa Fe (City), Santa Fe County (County), and Las Campanas Santa Fe (Las Campanas), is intended to provide a new surface water diversion to meet critical water needs in the Santa Fe area.

The proposed point of diversion is along the east bank of the Rio Grande near the historic Buckman town site, about 15 miles northwest from the City of Santa Fe, New Mexico (Figure 1). The proposed point of diversion is hereinafter referred to as Buckman. Buckman is about 3 miles downstream from where Route 4 crosses the Rio Grande at the Otowi Bridge, which is also the site of a U.S. Geological Survey (USGS) gaging station where streamflow has been recorded for more than a century. Besides the diversion structure at Buckman, a variety of water conveyance pipelines and several pump stations would be constructed, generally within existing utility easements that parallel or use Buckman Road, on U.S. Bureau of Land Management (BLM) lands, with smaller segments on U.S. Forest Service (USFS), Santa Fe County, state, and private lands. Buckman Road, from the community of Las Campanas to the Rio Grande, is approximately 11 miles of unimproved dirt roadway that serves as the only access to the Rio Grande in the USFS Española Ranger District.

From Buckman Road at "Dead Dog Well" within BLM lands, two raw water pipelines would diverge, one southeasterly to serve Las Campanas, and one southerly to serve the City and County. The Las Campanas leg would run about 5 miles utilizing Buckman Road and Camino la Tierra to a new private water treatment plant. The City/County leg run approximately 4 miles along existing rights-of-way that are adjacent to unimproved maintenance roadways. The City/County pipeline would terminate at the proposed regional water treatment plant approximately ¼-mile west of Caja del Rio Road within the northern confines of BLM land leased to the City for the City's MRC as shown in Figure 1.

The two new water treatment plants would be a 3-million gallon/day (mgd) plant at Las Campanas and a larger (15-mgd) plant for the City/County. New treated water pipelines would be installed from the treatment plants into the existing Las Campanas and City/County water distribution systems. [See CDM (September 2002) for other details of the proposed Project, the existing Santa Fe area water system, and a summary of water demands.]

Considerable preliminary engineering, feasibility study, and hydrologic evaluation of water supply alternatives have been undertaken for the Proponents by CDM (October 2001; September 2002) and CH2M HILL (October 2001). The above evaluations have led to the identification of a river intake on USFS land at Buckman as the proposed alternative for diverting water from the river for meeting the water needs of the Project. With the USFS and the BLM as co-lead federal agencies, an Environmental Impact Statement (EIS) is currently underway to evaluate the potential impacts of the proposed Project.

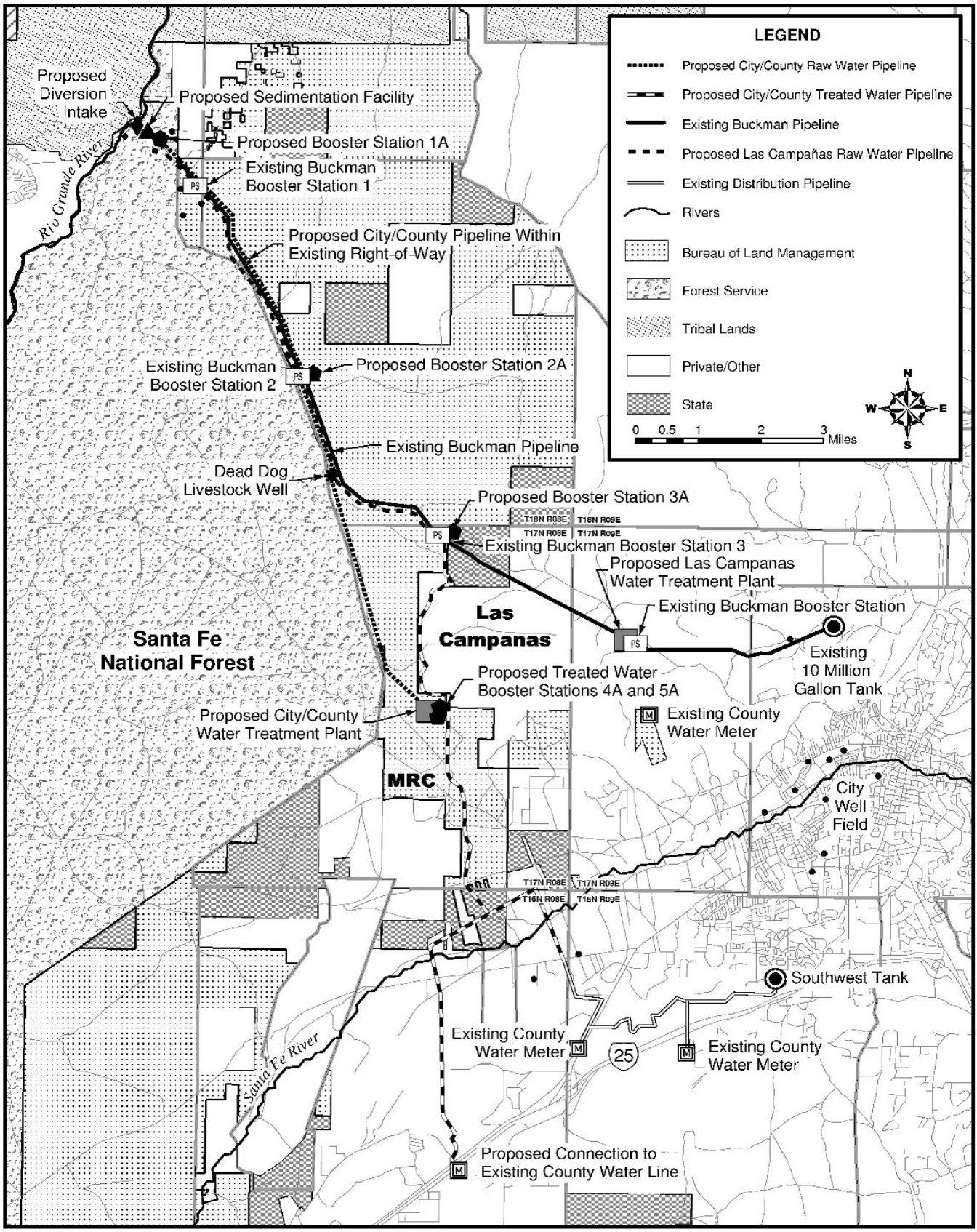


Figure 1. Buckman Project Location Map

The Buckman diversion facility will be located on the east bank of the Rio Grande just downstream of the terminus of Buckman Road (Figures 1 and 2). As shown in Figure 3, the facility would include a screened river intake (stainless steel fish screen with approximate 2.0-mm openings), low-head pump station, small electrical and control building, and any of several sediment removal/management options for dealing with the relatively high concentrations of suspended sediment carried by the Rio Grande.

A summary of the estimated maximum monthly average demands required to be met from the Buckman diversion facility in 2010 is provided in Table 1.

The intake facility will have a hydraulic capacity of up to about 32 cubic feet per second (cfs) based on the estimated peak daily demand of 28 cfs plus additional amounts for between zero and 'overpumpage' of carriage water. Under the Sand-Return option depicted in Figure 3 and described later, up to 4 cfs of carriage water (consisting of river water with ambient sediment and turbidity concentrations) would be used for returning removed sand to the river just below the intake facility. Under the other four options considered in this report, carriage water would not be required or diverted.

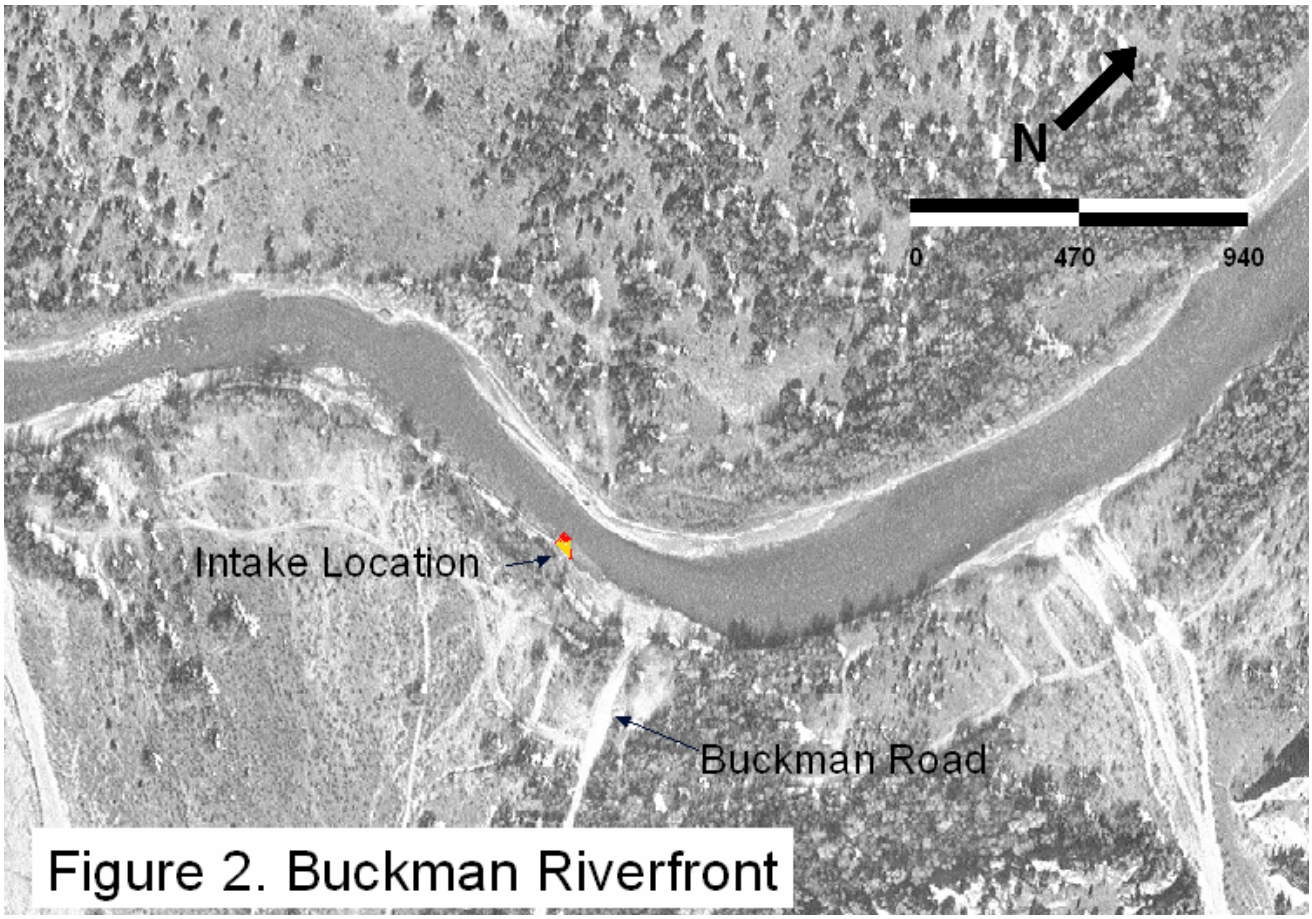
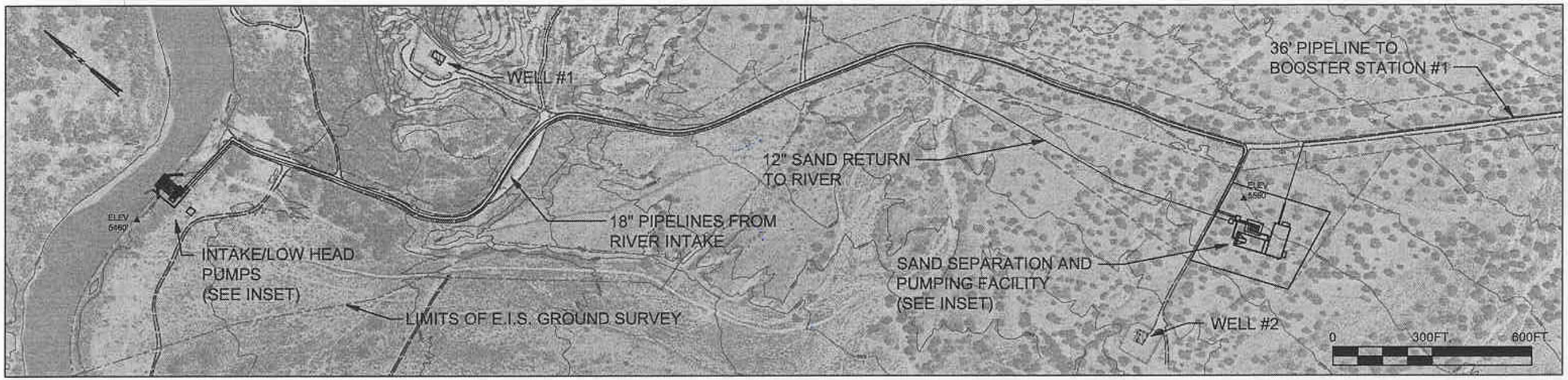
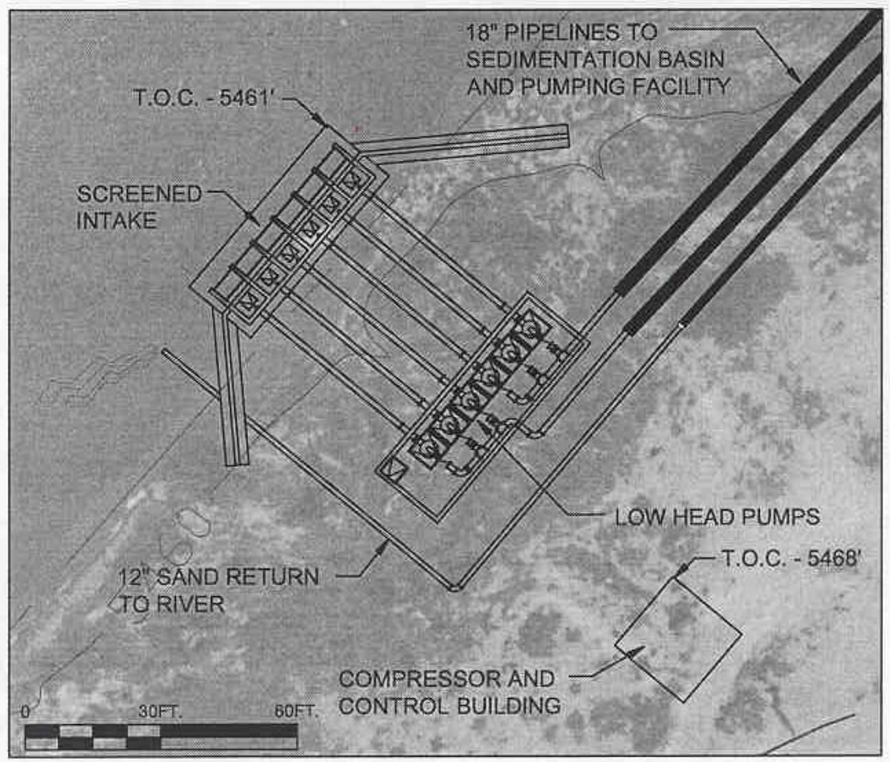


Figure 2. Buckman Riverfront





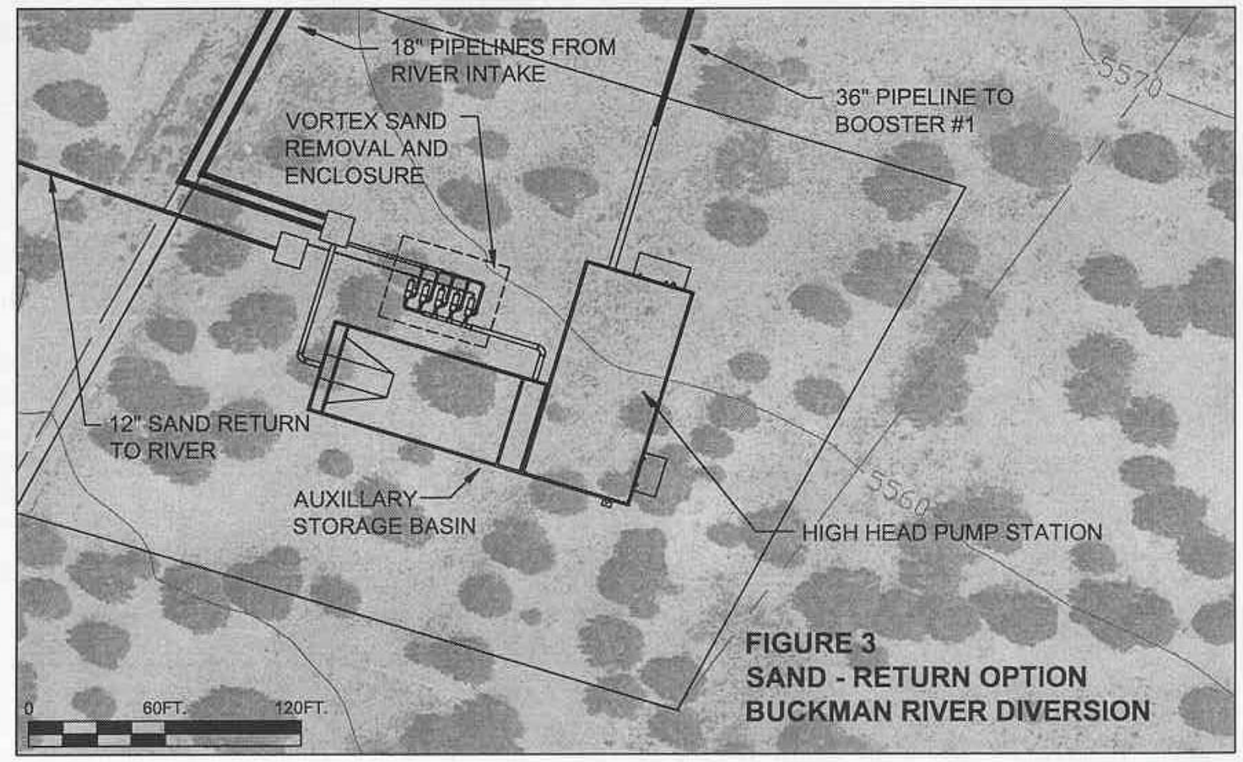


FIGURE 3
SAND - RETURN OPTION
BUCKMAN RIVER DIVERSION

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Table 1. Estimated 2010 Maximum Annual and 2010 Peak-Day Drought Year Demands for the Buckman Diversion Project

Water User	Max. Annual Demand (ac-ft/yr)	Peak Day Demand (mgd)	Peak Day Demand (cfs)
Santa Fe City/County	6,930	15.0	23.2
Las Campanas	1,800	3.2	5.0
Total	8,730	18.2	28.2

Note: ac-ft/yr = acre-feet per year.

Month	Percentage of Peak-Day Demand in Stated Month[a]	Max. Monthly Average Demand[b] (mgd)	Max. Monthly Average Demand[b] (cfs)
January	0.40	7.3	11.3
February	.45	8.2	12.7
March	.50	9.1	14.1
April	.65	11.8	18.2
May	.85	15.4	23.8
June	1.00	18.2	28.2
July	.93	16.9	26.1
August	.85	15.4	23.8
September	.80	14.6	22.6
October	.70	12.7	19.6
November	.50	9.1	14.1
December	.40	7.3	11.3

[a] Estimated from recent records provided by City of Santa Fe.

[b] It is unlikely that maximum monthly demands listed would occur in consecutive months. Values presented in this table are estimates of the highest probable use of the diversion in any given month (monthly average basis).

Purpose and Scope

The purpose of this report is to describe and compare alternatives for management of sediment diverted from the river at the proposed Buckman diversion facilities. Five options were initially considered:

- Two "Pumping" options, each involving pumping of all removed sediment up the raw water conveyance system to the new City/County water treatment plant and to Las Campanas;
- Two "Storage-Trucking" options involving near-river removal, storage, and trucking of sand-sized materials (>0.1 mm) to the Caja del Rio landfill in Santa Fe;
- One "Sand-Return" option involving near-river removal and return of the sand-sized (>0.1-mm) materials to the river just below the proposed river intake.

As described subsequently, an evaluation of the five options resulted in the identification of the Sand-Return option as the only feasible option for implementation. Because of the need for a National Pollutant Discharge Elimination System (NPDES) permit for the discharge of settled sand back to the Rio Grande, the Sand-Return option was presented to and discussed with officials of the Surface Water Quality Bureau, New Mexico Environment Department (NMED) in summer 2002 and January 2003, and to U.S. Environmental Protection Agency (EPA) Region 6 officials in November 2002. In the meeting with EPA, it was suggested that supplemental documentation of Project sediment removal/management alternatives was needed to better document the justification for the Sand-Return option. Thus, this report is intended as a technical supplement to a draft NPDES permit application to EPA as the basis for additional justification for the proposed Sand-Return option. Of particular interest are three issues:

1. The minimal effect of the diversion and sand return on the concentration and load of total suspended solids and turbidity in the river just downstream of the intake.
2. The extent of sediment storage and disposal facilities, associated trucking of sediment and roadway improvements required under the Storage-Trucking option, and technical, economic, and environmental concerns associated with this option.
3. The technical and operational infeasibility of the "pumping" options.

Besides the Project Background section presented above, the report includes the following major sections:

- Description of Project options for suspended sediment management
- Overview of streamflow and suspended sediment characteristics of river water in the Buckman Project area
- Evaluation and comparison of sediment management options, including pros and cons and estimated costs
- Summary of conclusions

Companion reports (CH2M HILL, February 2003a; February 2003b) summarize streamflow and sediment characteristics of the Rio Grande at Buckman and evaluated possible effects of Project operation on flows and sediment concentrations below the proposed diversion. Excerpts of those reports are provided in Appendix A.

Sediment Management Options

As described in Appendix A, the Rio Grande is characterized by extremes in seasonal streamflow and suspended sediment concentrations. Data collected at the USGS gage at Otowi, a few miles above Buckman, suggest that the river transports an average of more than 4,000 tons per day of suspended sediment by the proposed Buckman diversion site. On some days more than 10 times as much can be transported by the river, while on others less than a tenth as much.

Like the river, diverted water will contain considerable quantities of suspended sediment – approximately 1,200 milligram per liter (mg/L) on average based on evaluation of the historic record at Otowi (see Appendix A). This sediment, particularly the sandy materials in the grain-size range >0.1 mm in diameter, can cause troublesome design and operational problems with pumps and conveyance pipelines. Sand can cause severe abrasion of pump bowls, seals, bearings, and impellers — particularly in applications requiring high pumping lifts (e.g., >300 feet) such as those needed for the Project conveyance line from Buckman to the proposed City/County water treatment plant, and to Las Campanas. Total heads estimated for the Buckman delivery system are more than 1,500 feet in 3 to 4 lifts, depending on delivery point. Thus, removal of as much sand as practicable before pumping is highly desirable. Failure to do so will result in frequent replacement of pump bowls and impellers, low pump efficiencies (high power costs), and significantly more O&M complexity and cost.

Besides the problems with pumps, failure to remove sand in the conveyance system (i.e., all material >0.1 mm in diameter) will result in settling in pipelines and water tanks at each of the proposed Project booster pump stations. Much of the material smaller in diameter than 0.1 mm (silts and clays) can probably be kept in suspension in the pipeline; or upon settling during periods of lower flow rates, re-suspended and moved along by operating the system periodically at high flow rates (4 to 5 feet per second in velocity). However, the material >0.1 mm that settles in the pipeline and water tanks would be very difficult to manage.

Screening of Options

In the course of Project planning, the Proponents' consulting engineers (CH2M HILL and CDM) considered a number of options for managing the suspended sediment in river water diverted at the proposed Buckman facility. Five primary options were originally considered as listed below and further detailed later. Note that each option includes a 28.2-cfs (net) diversion at Buckman as described previously.

A detailed cost estimate for each of the five options was not developed. Rather, the options were compared based upon estimated increases in Project costs for sediment management, with common costs excluded. Criteria used in the assessment of these options included: costs (capital and O&M); river water quality; technical/operational feasibility; ; permitting considerations; and quality of life issues — traffic, safety, noise, aesthetics. Several of these issues are being evaluated in more detail as part of the ongoing EIS for the Buckman Project.

Option 1. Pump All Sediment in Conveyance Pipeline (All Pumping Option)

In Option 1, diverted river water with its full suspended sediment load (estimated at about 1,200 mg/L on average, see Appendix A), would be pumped up the conveyance system to the new City/County water treatment plant, and to Las Campanas. This would not affect river water quality and would minimize near-river land requirements (i.e., only a small auxiliary sediment pond and no other sediment removal equipment). However, sediment deposition and abrasion in the raw water conveyance facilities (pipelines, tanks, pump stations) make this option technically and operationally infeasible.

The high sediment load would lead to heavy wear of pumps — pump life could easily be reduced by 50 percent. This option also would require an extensive and carefully controlled program of surging, flushing, and blow-off to re-suspend and/or remove sediments from the conveyance lines and intermediate tanks along the conveyance route. Tank agitators, sizeable blow-off storage ponds, and considerable trucking of flushed sediments would be required at points along the conveyance route. There would be an increased frequency of system shutdowns, the need for additional land and right-of-way along the conveyance route, and generally more unsightly conditions caused by the presence of sediment storage ponds and blow-off facilities at multiple locations. Preliminary hydraulic evaluation suggests that to be even remotely feasible, dual 20-inch conveyance lines (rather than the single 36-inch line now contemplated) would be necessary.

Pipeline construction and other added conveyance facility costs could easily be more than $10 million above the Project capital costs estimated by CDM (September 2002, CDM Report). Annual O&M costs would also be substantially more — our rough estimate is an additional $1.0 million per year.

In view of the technical and operational infeasibility — very substantial O&M requirements, capital and operating costs, trucking and safety issues, and uncertainties in long-term reliability — Option 1 was determined to be not viable and eliminated from further consideration.

Option 2. Collect >0.1-mm Sediment and Pump in Separate Pipeline (Slurry-Line Option)

Termed the "Slurry-Line" option, this would involve the collection of >0.1-mm material in a "grit chamber" type facility (about 50 feet by 70 feet by 10 feet) built onto the back of the river intake at the Buckman diversion site. The sand collected in the "grit chamber" would be conveyed in a separate 6-inch to 8-inch pipeline parallel to the main water conveyance pipeline and pumping system to the City/County water treatment plant where it would be removed in sedimentation ponds. The material <0.1 mm in size would remain with the water in the main conveyance pipeline.

The Slurry-Line option would result in no changes in river water quality, but would, like Option 1, result in increased land and right-of-way requirements along the conveyance route. Because it would be conveying concentrated sand, relatively low efficiency pumps would be required, and pump stations could not necessarily be located coincident with the main conveyance pumping facilities. Also, a relatively sophisticated control and variable frequency drive system would be needed to ensure continuous movement of the sediment

slurry. The reliability of the separate pumping, pipeline, and grit chamber facilities is questionable. Construction of the grit chamber would entail additional excavation and dewatering and add to construction complexity in a sensitive near-river area.

We estimate that construction of the Slurry-Line conveyance system (assuming it could be determined reliable) cost could add $6 million to $7 million to the Project costs. Annual O&M costs would also be significant — our rough estimate is an additional $0.3 to $0.4 million per year. There would also be additional near-river truck traffic to the river intake site to maintain the grit chamber and additional space and sediment handling requirements at the City/County water treatment plant.

Because of the many operational uncertainties, potential construction difficulties, and likely high costs of what is essentially an unproven concept for sediment separation, the Slurry-Line option was considered to be technically infeasible and was eliminated from further consideration.

Option 3. Remove >0.1-mm Sediment and Return to River (Sand-Return Option)

The Sand-Return option would entail the pumping of all water and sediment from the intake via low-lift pumps approximately 100 feet in elevation above and ½ mile up Buckman Road to an area near Buckman Well No. 2 (see Figure 3). There, the >0.1-mm material would be removed using mechanical, vortex (centrifugal) separators. The removed material would be returned to the river in a 12-inch line along with 2 to 4 cfs of ambient river water diverted from the intake and circulated on a continuous basis. The return flow would be "jetted" into the river to promote mixing on the downstream side of the intake structure. The vortex separator units would be enclosed within a small building for freeze and security protection. Additionally, a relatively small (40 feet by 80 feet by 8 feet) auxiliary sediment pond would be located on the Well No. 2 site for emergency use as a backup to the vortex units. Because of the elimination of the need for onsite storage, land requirements would be reduced relative to the other sediment management options.

For purposes of evaluation of effects on river water quality, we examined flow rates of 200, 1,000, and 1,500 cfs and suspended sediment concentrations of 750, 1,600, and 1,950 mg/L (taken from the flow versus suspended sediment relationship shown in Appendix A, Figure A-6). These flows and concentrations were selected because examination showed that maximum changes in terms of upstream to downstream sediment levels occurred at lower flows. Thus, flows of 200 and 1,000 cfs are representative of extreme low and relatively low-flow conditions, respectively. The flow of 1,500 cfs is representative of the long-term average flow of the river at Otowi (see Table A-1, Appendix A), whereas the corresponding 1,950 mg/L suspended sediment concentration used in our analysis summarized in Table 2 is approximately 50 percent higher than the long-term mean suspended sediment concentration observed at Otowi.

Table 2. Summary of Suspended Sediment Mass Balances at 4-cfs Carriage Water and 30% and 40% Return Sand Concentration

Upstream Flow (cfs)	Carriage Water (cfs)	Return Sand [a] Concentration (%)	Net Diversion Rate (cfs)	TSS Upstream (mg/L)	Return Flow TSS (mg/L)	TSS Downstream (mg/L)	% TSS Increase in River Downstream
200	4	30	28	750	2,325	787	4.88
	4	40	28	750	2,850	799	6.51
	4	30	21	750	1,931	776	3.52
	4	40	21	750	2,325	785	4.69
	4	30	14	750	1,538	767	2.26
	4	40	14	750	1,800	773	3.01
	4	30	7	750	1,144	758	1.09
	4	40	7	750	1,275	761	1.45
1,000	4	30	28	1,600	4,960	1,614	0.86
	4	40	28	1,600	6,080	1,618	1.15
	4	30	21	1,600	4,120	1,610	0.64
	4	40	21	1,600	4,960	1,614	0.86
	4	30	14	1,600	3,280	1,607	0.43
	4	40	14	1,600	3,840	1,609	0.57
	4	30	7	1,600	2,440	1,603	0.21
	4	40	7	1,600	2,720	1,605	0.28
1,500	4	30	28	1,950	6,045	1,961	0.57
	4	40	28	1,950	7,410	1,965	0.76
	4	30	21	1,950	5,021	1,958	0.43
	4	40	21	1,950	6,045	1,961	0.57
	4	30	14	1,950	3,998	1,956	0.28
	4	40	14	1,950	4,680	1,957	0.38
	4	30	7	1,950	2,974	1,953	0.14
	4	40	7	1,950	3,315	1,954	0.19

[a] Given as a percent of total sediment concentration based on size analysis curve presented in Appendix A. Based on the curve, the 0.1-mm size fraction proposed for removal was about 25%. The analysis assumed an additional 5 to 15% of the sediment would be entrapped and returned (thus a 30-40% total return).

Table 2 indicates that the returned sand would have a very minimal effect on the river in terms of suspended sediment concentrations. For example, at the mean river flow condition of about 1,500 cfs (1971-2001 mean flow was 1,539 as indicated in Figure A-1, Appendix A),

the upstream-to-downstream increase in sediment concentration (after mixing) would be less than 15 mg/L under worst case assumptions — 1,500 cfs river flow, 1,950 mg/L upstream concentration, 40 percent sand fraction return (15 percent higher than expected based on typical size distribution shown in Figure A-5 of Appendix A), and a 28 cfs net diversion — results in an increase of sediment concentration from 1,950 upstream to 1,965 mg/L downstream. In over 90 percent of the time, the upstream-to-downstream increases would be less than 25 mg/L—virtually unmeasurable and insignificant relative to the range of naturally-occurring sediment concentrations in this reach of the Rio Grande.

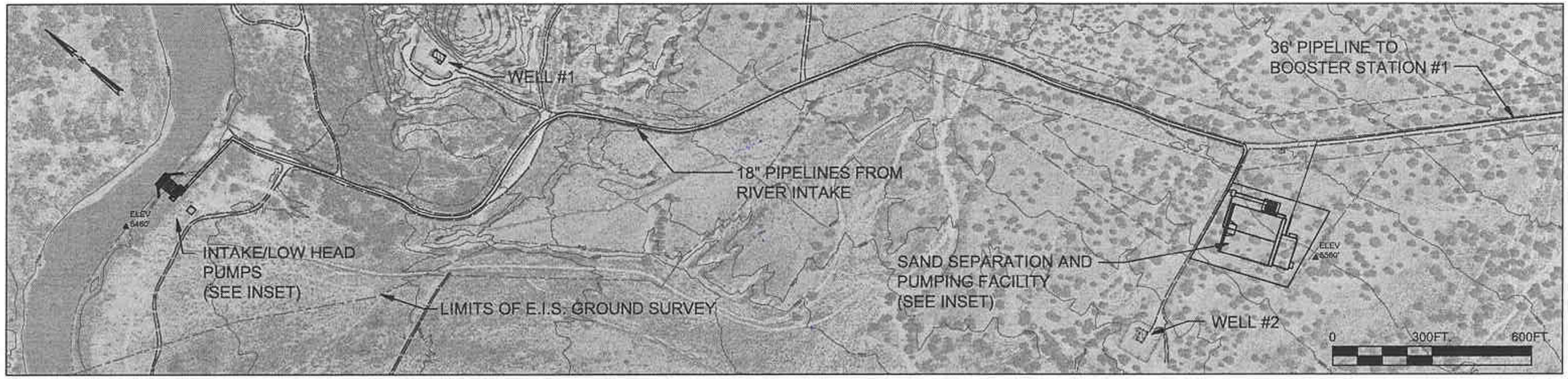
Like the other sediment management options, the Sand-Return option would result in a net decrease in solids *load* (i.e., tons/day) in the Rio Grande, in that the majority of solids diverted would still be pumped to the treatment plants. For this option, landfill impacts and associated disposal costs will be less than the other four options in that a portion of the sediment diverted will be returned to its natural source in the river, rather than having all sediment disposed at the landfill.

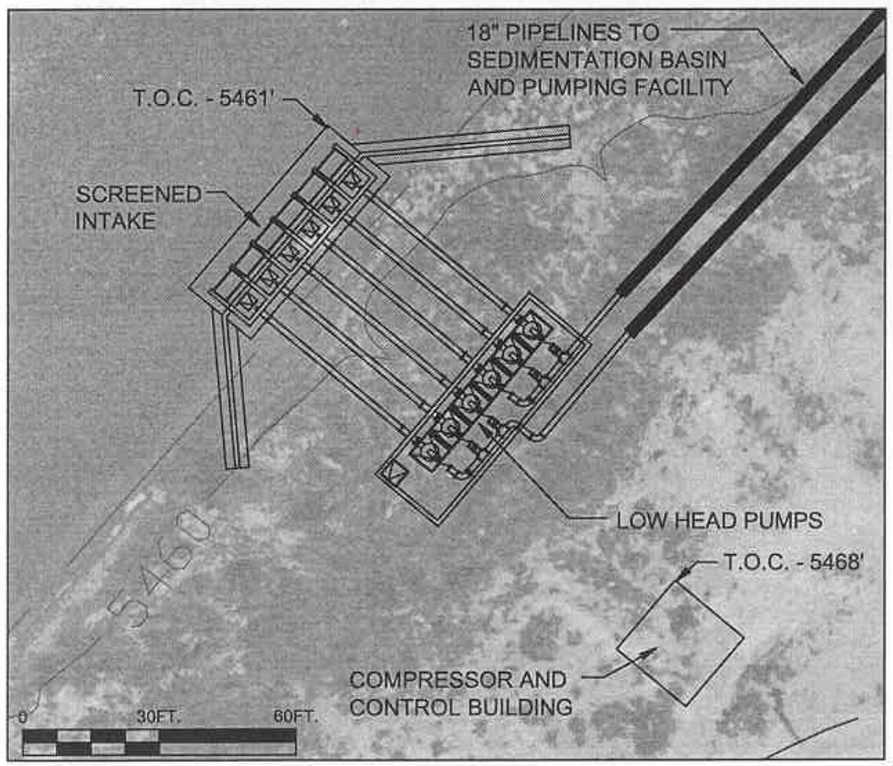
The Sand-Return option will require an NPDES permit, as well as additional scrutiny relative to water quality in the 404 and State Engineer diversion permitting process. Thus, river-related permitting will be more involved than for any of the other sediment management options considered here. Other advantages of the Sand-Return option include: minimal near-river facilities, reduced truck traffic on Buckman Road and near the river, and relatively low visibility/aesthetics issues since all sediment management facilities can be located near Well No. 2 away from the river and not visible from the White Rock overlook (this issue being important for the USFS-controlled viewshed in the area). We estimate that the Sand-Return option would add less than $1 million to the Project costs. Annual O&M costs, including permitting administration should be less than an additional $0.1 million per year. We estimate that construction and O&M costs of the Sand-Return option would be substantially lower than any of the other options considered here.

Despite the increased permitting requirements, the Sand-Return option was considered viable and considerably more advantageous than the other four options with respect to construction cost, O&M issues, environmental, safety, and other 'non-cost' considerations.

Option 4. Remove >0.1-mm Sediment, Store, and Truck (Storage-Trucking Option)

The Storage-Trucking option would, like Option 3, use vortex separators located near Well No. 2 to remove the >0.1-mm material from the diverted river water (similar to Option 3). However, as shown in Figure 4, instead of returning the removed sand to the river as in Option 3, the sand would be discharged to lined ponds for storage, drying, and eventual trucking to disposal at the Caja del Rio landfill near the City/County water treatment plant. The lined ponds, based on estimated sediment loading of the material >0.1 mm plus an additional 5 percent entrapment of smaller sediments, would require two ponds of about 75 feet by 150 feet by 8 feet. One pond would be in operation, receiving sand from the vortex separators on a continuous basis, the other would be used for storage and drying. About twice a year, the dried sand would be removed by trucking and disposed to the Caja del Rio landfill — approximately 20 miles one way. It should be noted that neither the BLM nor USFS has given any indication that they would allow a permanent disposal area for the removed sand at a more local site.





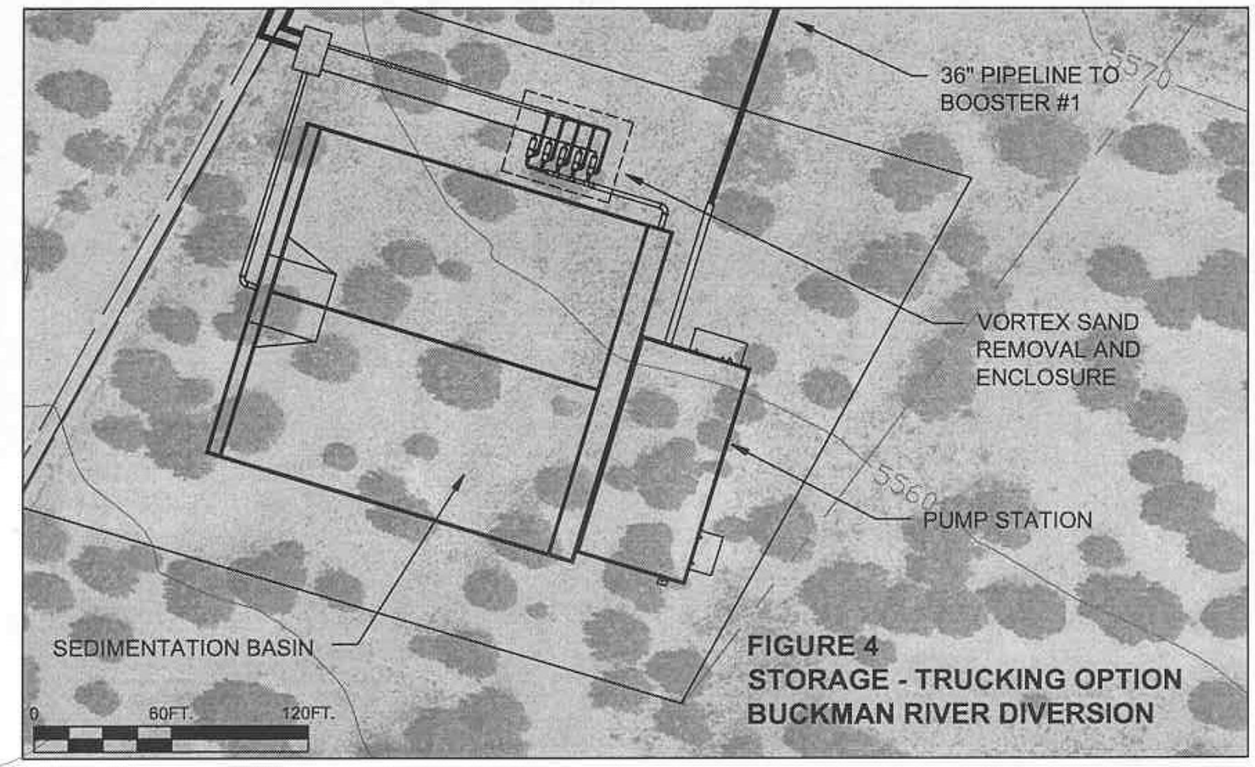


FIGURE 4
STORAGE - TRUCKING OPTION
BUCKMAN RIVER DIVERSION

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Our evaluation indicates that, on average, about 400 truck trips per year (12-yard load) will be needed to remove the dried sand from the pond system. In some years, more than 1,000 truck trips would be needed. Average annual cost of the loading and trucking operation has been roughly estimated at $250 to $300 per trip, or $100,000 to $120,000 per year. We believe that a minimally improved Buckman Road (as presently proposed — new base course and 4 inches of gravel) could not begin to withstand the anticipated truck traffic. Additionally, the road would have to be straightened for safety concerns. There are presently several severe hairpin turns and blind spots that would preclude the safe operation of large trucks (Cliff Walbridge, C.R. Walbridge Engineers, verbal communication, March 21, 2003). Paving, widening, and straightening would almost certainly be required for a viable, long-term Storage-Trucking option. Estimated cost for a 22- to 24-foot-wide paved road, roughly 11 miles, are on the order of $4.0 to $4.5 million.

For numerous reasons, this option was not considered viable. These include:

- Significantly higher capital and operational costs relative to other options cannot be justified;
- Anticipated BLM and public opposition to necessary road widening, paving, straightening, and associated tree removal and other construction impacts;
- Increased sediment disposal at the landfill relative to Option 3, rather than returning solids to the river;
- Traffic and safety concerns associated with road improvements, increased vehicular speeds, and significant truck traffic;
- Environmental and quality-of-life impacts, including reduced air quality and increased noise in a sensitive recreational and environmental area, and in residential areas along the truck haul route.

The Storage-Trucking option, while considered technically possible, would be considerably more costly than the Sand-Return option. It also raises severe concerns regarding traffic safety, noise, and air quality in a sensitive near-river area and in residential areas along the haul route.

Option 5. Remove All Sediment, Store, and Truck (All Storage-Trucking Option)

The All Storage-Trucking option would not utilize vortex separators to remove selected material from the water diverted at Buckman. Instead, the entire sediment load would be conveyed into two large sedimentation basins near Well No. 2. The two basins, each 150 feet by 300 feet by 8 feet would be needed to efficiently remove, store, and dry the sediment. About twice a year, the dried sand would be removed by trucking and disposed to the Caja del Rio landfill — approximately 20 miles one way. (Again, neither the BLM nor USFS has given any indication that a permanent disposal area for the removed sand can be found on local or federal land.)

Our evaluation indicates that, on average, about 1,200 truck trips per year (12-yard load) will be needed to remove the dried sand from the pond system. In some years, more than 3,000 truck trips would be needed. Annual average cost of the loading and trucking operation has been roughly estimated at $250 to $300 per trip, or $300,000 to $360,000 per

year. Even more so than Option 4, a minimally improved Buckman Road (as presently proposed by — new base course and 4 inches of gravel) would be totally inadequate to withstand the anticipated truck traffic. Widening, paving, and straightening would be a necessity for a, long-term All Storage-Trucking option. Estimated cost for a 22- to 24-foot-wide paved road, roughly 11 miles, are on the order of $4.0 to $4.5 million.

The large sediment ponds would add to unsightly conditions and land requirements. They would be visible from Buckman Road and the White Rock overlook. Each of the other negative impacts mentioned for Option 4 would also be present, but to a large extent.

Option 5 was not considered viable and is the most costly of all the options considered. Due to the increased number of truck trips required, it raises even more concerns regarding traffic safety, noise, and air quality in a sensitive near-river area and residential areas than does Option 4.

Identification of Preferred Sediment Management Option

The pros and cons and considerations of the sediment management options described above were assigned numerical rankings for the screening criteria mentioned in the previous section on ***Screening of Options***. These included rankings for: costs, river water quality, technical/operational feasibility, permitting considerations, and quality of life issues — traffic, safety, noise, aesthetics. Final comparative rankings of the five options are summarized in Table 3.

As indicated in the discussion above and as indicated in Table 3, three of the options were considered infeasible. Option 1—All Pumping and Option 2—Slurry-Line were deemed infeasible for technical/operational reasons. Option 5—All Storage-Trucking was considered infeasible for reasons of impacts due to traffic, safety, noise, aesthetics, and air quality.

Consequently, only Option 3—Sand-Return, and Option 4—Storage-Trucking were considered feasible. Option 3 with a numerical ranking of 11 is clearly superior to Option 4 ranked at 16. This is primarily due to the problems involved in dealing manually with 5,000 tons per year (or more) of suspended sediment, massive trucking requirements, and the large land requirements on federal property.

Based on the comparison and evaluation described above, the Sand-Return option (Option 3) is the least expensive and most advantageous of those options for managing sediment in the Buckman Project. The use of vortex separators, relatively small-lined storage ponds, and a sand-return/jetting system should be reasonably easy to maintain and have insignificant effects on river water quality.

Table 3. Final Ranking Summary of Sediment Management Options

Sediment Management Option	Cost	Technical-Operational Feasibility	River Water Quality	Permitting Issues	Traffic, Safety, Noise, Aesthetics, Air Quality	Total Score
1. All Pumping	5	X	1	2	3	X
2. Slurry-Line	4	X	1	2	3	X
3. Sand Return	1	2	3	4	1	11
4. Storage-Trucking	4	4	1	2	5	16
5. All Storage-Trucking	5	5	1	3	X	X

1—clearly best; 2 – good; 3—neutral; 4—unfavorable; 5—clearly worst; X – infeasible (unacceptable)

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Appendix A.
Rio Grande Streamflow and Sediment Characteristics

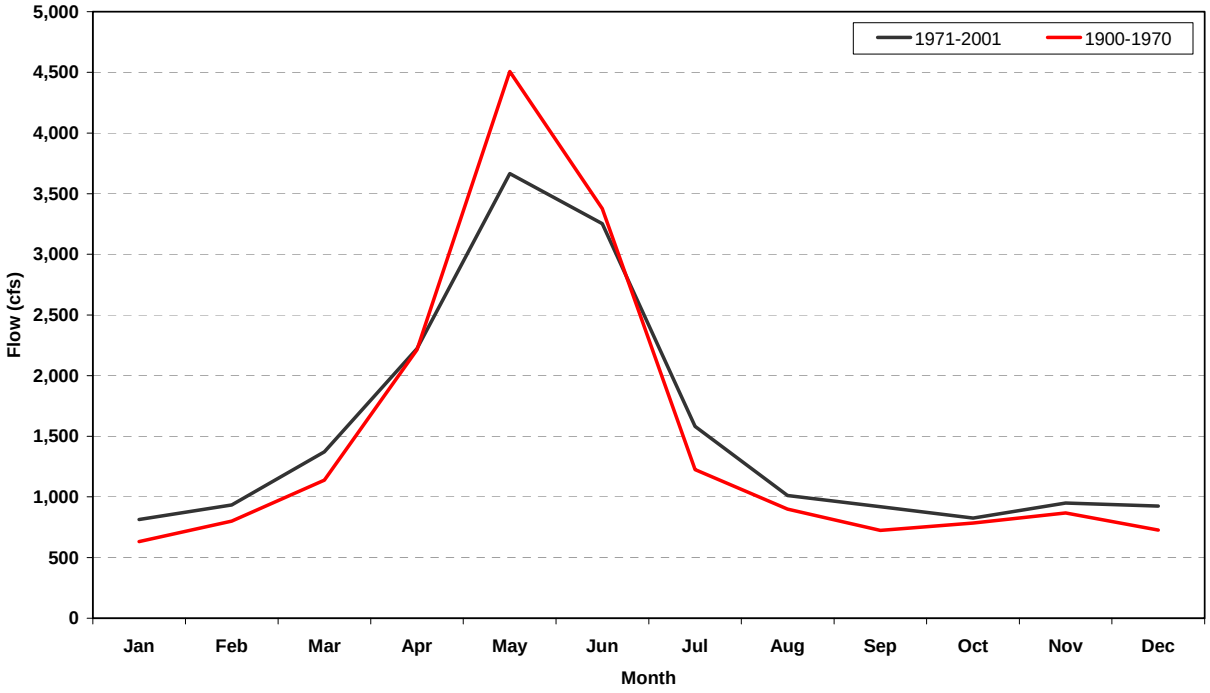
Streamflow Characteristics

Previous reports by CH2M HILL provided details on river hydrology and sedimentation for the Rio Grande in the Buckman area. These reports are entitled *Hydrologic Issues Related to the Proposed Surface Diversion on the Rio Grande at Buckman* (CH2M HILL, February 2003a) and *Evaluation of Sand-Return Option for Buckman Diversion Project, NM* (CH2M HILL, February 2003b). Excerpts from these reports are provided in this appendix for reference. Only the major findings of these reports are provided in the following two sections.

The proposed Project intake is located on the Rio Grande at Buckman some 3 miles downstream of the State Highway 4 Bridge at Otowi. The USGS gage at Otowi has one of the longest and most complete records of streamflow in the United States, with daily flow data available from 1895 to present (uninterrupted since 1900)..

The seasonal runoff pattern of the river at Otowi is shown in Figure A-1. The snowmelt runoff period generally begins in late March or early April and proceeds to a peak in May or June. After June, streamflow at Otowi usually declines through July and August ,and then to a base flow of less than 1,000 cfs for much of the September to February period. The July-September period is often marked by thunderstorms runoff with resulting high suspended sediment concentrations.

Figure A-1. Mean Monthly Flow at Otowi,1971-2001



The long-term record of annual flows at Otowi shows that river discharge has averaged about 1,510 cfs (1.09 million ac-ft/yr) over the 1900-2001 period and 1,539 cfs over the 1971-2001 period (see Table A-1, which provides monthly flows for the Rio Grande at Otowi for the 1971-2001 period). Note that minimum monthly flows of record, 260 to 360 cfs, occurred in September and October. From Figure A-1 and Table A-1, the seasonal flow pattern of the Rio Grande at Otowi from 1971-2001 can be characterized as follows:

- Fall-winter, low flow — September through February; September and October have flows augmented somewhat by irrigation releases and occasional thunderstorms. Mean flows typically 850 to 950 cfs, minimums typically 260 to 500 cfs.
- Pre-snowmelt, moderate flow — March and April; early snowmelt can begin in April in some years. Mean flows typically 1,400 to 2,300 cfs, minimums 500 to 600 cfs.
- Spring snowmelt, high flow — May and June; snowmelt can extend into July in wet, cooler years. Mean flows generally 3,300 to 3,800 cfs, minimums can be as low as 450 to 500 cfs in years of poor snowpack, but more typically are about 1,000 cfs.
- Summer monsoon, moderate flow — July through August; mean flows typically 1,000 to 1,500 cfs, but can be as low as 400 and as high as 3,000 cfs depending on strength (or lack of) monsoon.

Year	January Average (cfs)	February Average (cfs)	March Average (cfs)	April Average (cfs)	May Average (cfs)	June Average (cfs)	July Average (cfs)	August Average (cfs)	September Average (cfs)	October Average (cfs)	November Average (cfs)	December Average (cfs)	**Annual Average (cfs)**
1971	721	877	1,141	1,215	898	528	568	463	396	910	1,151	735	**800**
1972	688	862	1,274	741	433	470	394	391	449	689	1,020	734	**679**
1973	685	692	1,161	1,851	5,514	4,909	3,125	1,612	1,033	845	922	1,681	**2,003**
1974	1,326	717	1,161	936	1,032	1,031	668	769	263	361	429	450	**762**
1975	473	562	956	2,078	3,680	4,023	2,681	968	976	821	1,485	1,959	**1,722**
1976	1,046	695	897	1,342	2,611	1,430	1,168	1,009	979	470	434	510	**1,049**
1977	436	526	612	489	639	1,162	838	633	467	493	401	488	**599**
1978	445	500	671	877	2,830	2,419	1,110	811	536	441	686	672	**1,000**
1979	565	649	1,683	3,506	6,616	7,914	3,579	1,169	741	819	1,618	1,477	**2,528**
1980	677	866	1,018	2,570	6,351	5,943	1,954	786	545	490	1,296	1,391	**1,991**
1981	688	590	631	606	833	956	735	642	415	564	740	581	**665**
1982	558	659	1,064	2,087	4,105	4,125	1,425	1,189	1,547	1,026	1,009	878	**1,639**
1983	746	954	1,475	2,480	5,054	6,162	3,087	952	704	527	589	1,036	**1,980**
1984	717	730	1,462	3,060	6,786	4,601	1,038	895	722	732	1,026	1,025	**1,900**
1985	993	1,021	2,346	6,412	8,390	6,471	1,503	1,081	1,047	1,218	1,272	1,252	**2,751**
1986	1,757	2,510	2,328	3,782	4,441	5,776	3,230	704	876	1,373	2,034	1,606	**2,535**
1987	1,294	2,641	3,127	5,225	7,285	4,219	1,500	1,379	1,532	1,554	1,399	763	**2,660**
1988	701	772	1,470	1,910	1,725	1,103	749	854	808	522	811	752	**1,015**
1989	731	810	2,026	3,397	1,653	844	1,023	807	586	558	476	575	**1,124**
1990	550	619	878	1,062	1,693	1,056	1,093	919	1,065	769	1,103	851	**972**
1991	848	1,063	1,524	3,055	4,562	3,460	1,390	1,523	1,115	692	1,215	1,129	**1,798**
1992	862	1,033	1,784	3,968	3,734	2,899	1,240	1,076	1,161	860	624	708	**1,662**
1993	900	1,140	1,559	3,101	5,518	4,806	1,629	1,213	1,328	836	1,259	1,243	**2,044**
1994	878	869	1,603	3,476	5,881	4,026	1,037	818	866	853	737	945	**1,833**
1995	974	1,243	1,945	2,301	4,682	6,484	4,548	1,009	1,046	1,127	1,258	1,034	**2,304**
1996	1,176	1,300	1,305	872	1,169	1,122	806	847	758	603	538	611	**926**
1997	707	857	1,474	1,569	4,274	4,389	1,340	1,209	1,467	2,225	1,382	1,012	**1,825**
1998	949	967	1,349	1,702	3,570	1,840	1,336	1,203	1,284	966	780	746	**1,391**
1999	798	779	765	1,015	3,603	3,086	1,514	2,132	1,553	1,040	804	725	**1,485**
2000	772	798	987	1,123	1,333	1,603	1,470	1,347	1,164	552	465	525	**1,012**
2001	543	618	830	1,130	2,748	1,957	1,239	977	1,052	694	454	574	**1,068**

1971-2001 Summary

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minimum	436	500	612	489	433	470	394	391	263	361	401	450	**599**
95% Daily Min.	448	518	637	552	506	515	391	340	268	313	401	430	**NA**
Maximum	1,757	2,641	3,127	6,412	8,390	7,914	4,548	2,132	1,553	2,225	2,034	1,959	**2,751**
Mean	813	933	1,371	2,224	3,666	3,252	1,581	1,013	919	827	949	925	**1,539**
Median	731	810	1,305	1,910	3,680	3,086	1,336	968	976	769	922	763	**1,639**
Std. Dev.	286	483	565	1415	2206	2128	989	350	363	382	410	385	**641**

Table A-1. Monthly Rio Grande Flows at Otowi, 1971-2001

Low-Flow Frequency and Basis of Intake Design

As a basis for the operational design of the river intake at Buckman, a low-flow design value is necessary. From inspection of the Otowi flow record, it was determined that only a few scattered days of flows less than 200 cfs had occurred since the mid-1960s at the Otowi gage. Thus, we reasoned that a flow of about 200 cfs was a good first approximation as a design low-flow value for the Buckman intake.

Surveys of the channel bottom and hydraulic analysis (Heggen, 2001) indicated that flows in the channel at the Buckman intake site should be sufficiently deep to permit operation at a peak diversion rate of 32 cfs (net peak diversion of 28.2 cfs after sand return) at a river flow of 200 cfs. With that conclusion in hand, it was left to estimate the likely frequency of a flow of 200 cfs at Otowi (assumed as identical to flows that would occur at Buckman). We applied standard USGS frequency analysis techniques (USGS – *Low Flow Investigations by H. C. Riggs, Chapter B1, Techniques of Water-Resources Investigation of the US Geological Survey, 1972*) to the hydrologic record at the Otowi gage. The analysis was based on the daily flow record for 1971-2001 [the post San Juan-Chama (SJC) project period] and a Gumbel-type power function fit to the gaged data.

Results are displayed in Figure A-2 in terms of recurrence frequency (in years) of consecutive mean daily low flows of 1, 7, 14, 30, and 60 days. The 7-day values are considered to be representative of those most likely to come into play in operating the diversion (i.e., operational decisions are likely to be made on the future weekly or biweekly streamflow and/or water demand outlook rather than on a day-to-day basis). Figure A-2 suggests that a consecutive 7-day low flow averaging 200 cfs might occur about once every 60 years[1].

Another important issue is when within a given year, a 7-day low flow is likely to occur. If such a flow occurred in June or July, when municipal water demands are normally highest, net diversion of up to 28.2 cfs would have a larger effect on river flows in the 200-cfs range. However, as indicated in Figure A-3, more than 50 percent of the 7-day low flows are most likely to occur in September and October – whereas virtually none are likely in June and only 7 percent of low flows are forecast to occur in July.

[1]In reality, post-2005 years are likely to see more SJC water in the river at Otowi than occurred previously, with a tendency to make less frequent the low flows predicted in the above analysis (Figure A-2). Under its proposed Drinking Water Project, Albuquerque will for the first time in SJC Project history be taking full delivery of its SJC supply from Abiquiu at an average of about 66 cfs. Similarly, the Santa Fe users will be taking a larger delivery of SJC water for this Project—up to nearly 7,000 ac-ft/yr (10 cfs on average and perhaps 28 cfs during peak periods). In contrast, records provided by Sangre de Cristo Water Company (Amy Lewis, written communication 2002,) suggests that releases of Santa Fe SJC for water rights offset purposes for Buckman pumping averaged only 1,560 ac-ft/yr over the 1971-98 period, about 2,000 ac-ft/yr in the last decade.

Figure A-2. Frequency Curves of annual lowest mean discharge for consecutive days at Otowi gage on Rio Grande

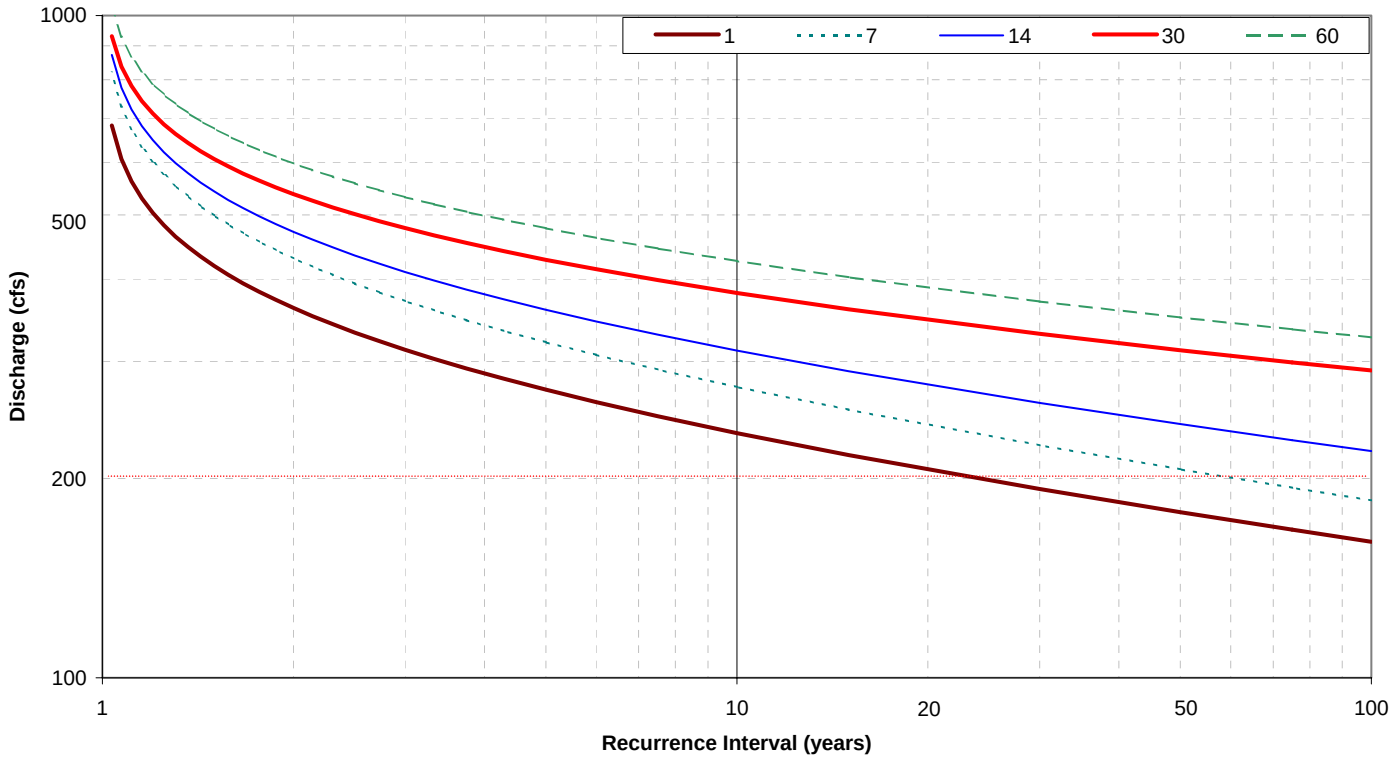


Figure A-3. Reccurence of 7-Day Low Flow by Month, 1971-98

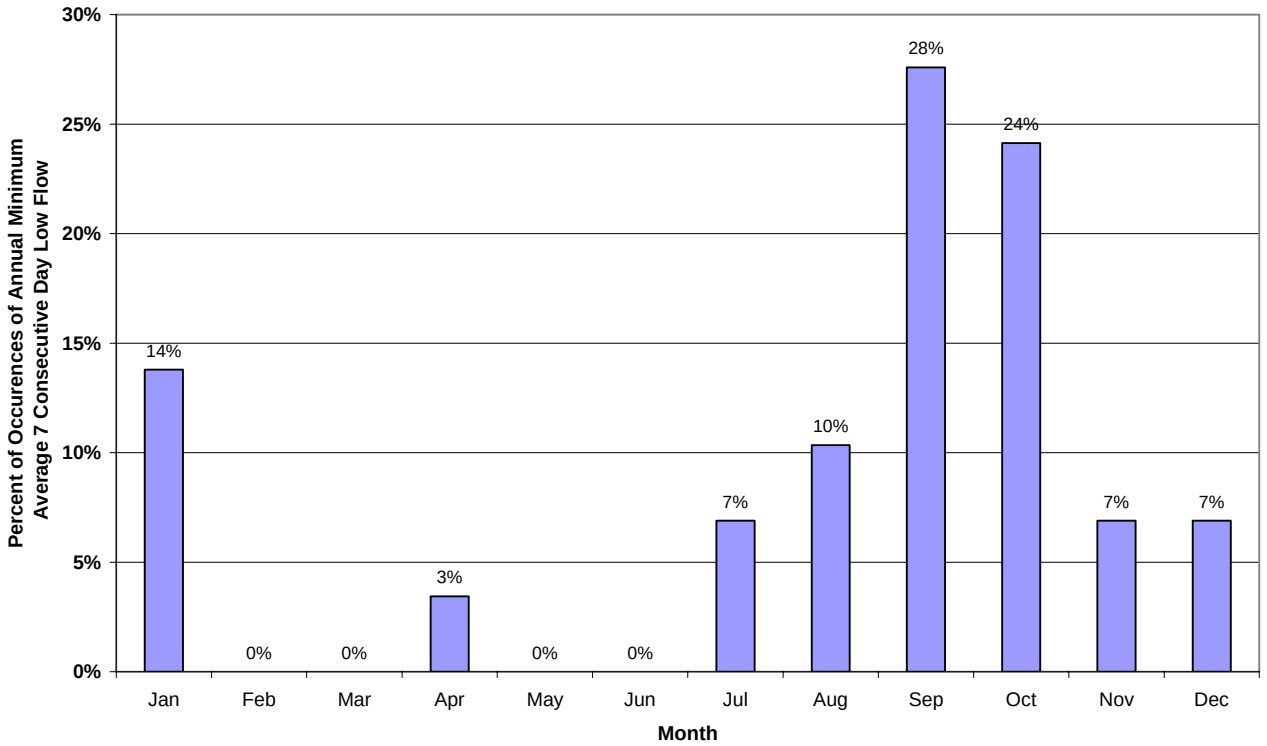


Table A-2 summarizes various values and indices of observed 1971-2001 Rio Grande flows and their relation to proposed maximum Buckman diversions on a monthly basis. Note that the proposed maximum diversions are a very small percentage (generally <2 percent) of median monthly river flow. In comparison to the 95th percentile minimum daily river flow, the maximum proposed Buckman diversions comprise about 2 to 8 percent (the latter in September) of 95th percentile minimum daily river flow.

Table A-2. Relationship of Proposed Buckman Diversions to Rio Grande Flow

Month	Max. Monthly Net Diversion (cfs)	1971-2001 Otowi Flow		Diversion as % of:	
		95th Percentile Daily Minimum Flow (cfs)	Median Monthly (cfs)	95th Percentile Daily Minimum Flow	Median Monthly Flow
January	11.3	448	731	2.5	1.5
February	12.7	518	810	2.4	1.6
March	14.1	637	1,305	2.2	1.1
April	18.2	552	1,415	3.3	1.3
May	23.8	506	3,680	4.7	0.6
June	28.2	515	3,086	5.5	0.9
July	26.1	391	1,336	6.6	2.0
August	23.8	340	968	7.0	2.5
September	22.6	268	976	8.4	2.3
October	19.6	313	769	6.3	2.5
November	14.1	401	922	3.5	1.5
December	11.3	430	763	2.6	1.5

In summary, a 7-day low flow of 200 cfs and an estimated recurrence frequency of 50 to 60 years would seem to be reasonable values (and probably conservative) for purposes of low-flow operational design for a project river intake at Buckman. The 95th percentile daily minimum flow, based on analysis of historic records for the Otowi gage, is estimated at 268 cfs (with a likely occurrence in September). It is highly unlikely that a peak demand (i.e., peak diversion from a Buckman intake) of 28.2 cfs (June peak day) would occur coincident with a 50- to 60-year minimum monthly flow of 200 cfs or a 95th percentile daily flow of 268 cfs. Minimum monthly June flows at Buckman are likely to be over 300 cfs whereas 95th percentile daily low flows should be more than 500 cfs. It would appear that the likely period of maximum impact on the Rio Grande would occur in September when extreme minimum 7-day lows could approach 200 cfs and peak-day diversions could be as high as 22 to 23 cfs.

Suspended Sediment Characteristics

Suspended sediment data have been collected on a daily basis at the USGS gage at Otowi since 1955 and since 1946 on a periodic basis. From these data, a series of graphs relating flow to suspended sediment concentration was produced from the post-1955 record. Summation of the daily USGS sampling records for the post-1955 indicates a mean daily suspended sediment concentration of about 1,200 mg/L. Our evaluation (CH2M HILL, February 2003b), as well as an earlier study by Heggen (2001), indicated that while there was a general relationship wherein daily suspended sediment concentration increased with increasing flow, the relationship was highly variable and often not predictable.

Consequently, we collated the daily flow and suspended sediment into monthly averages in an attempt to develop a better general relationship. This resulted in the data depicted in Figure A-4 for observed average monthly flow versus observed average monthly suspended sediment concentrations at the Otowi gage. An 'upper-bound' curve was drawn, which appears to be reasonable for purposes of conservatively estimating suspended sediment concentrations as a function of flow. The curve in Figure A-4 was used to estimate suspended sediment concentrations for river flows ranging from 200 to 5,000 cfs.

As described previously, the project is intended to remove and return the >0.10-mm sand fraction of the suspended sediment to the river. Thus, an estimate of the relative percentage of the >0.10-mm size fraction was needed. Figure A-5 shows the available USGS data for size analysis from samples taken from the Otowi sampling site. Figure A-5 indicates that the >0.10- mm sand fraction varies widely, but that, on average, was about 25 percent of the total suspended sediment concentration. Evaluation of individual concentrations versus river flow indicated no strong relationship between flow and percent sand >0.1 mm—again suggesting that the percentage of >0.10-mm material remained about the same despite changes in flow and total suspended sediment concentration.

Figure A-6 depicts the observed general relationship between observed turbidity concentrations and suspended sediment concentrations based on the available data from the Otowi sampling site. Note that while the turbidity concentration increases with suspended sediment concentration, it is not linear (i.e., a ten-fold increase in suspended sediment concentration results in about a three-fold increase in turbidity).

Figure A-4. Flow Versus Suspended Solids Concentration, Rio Grande at Otowi

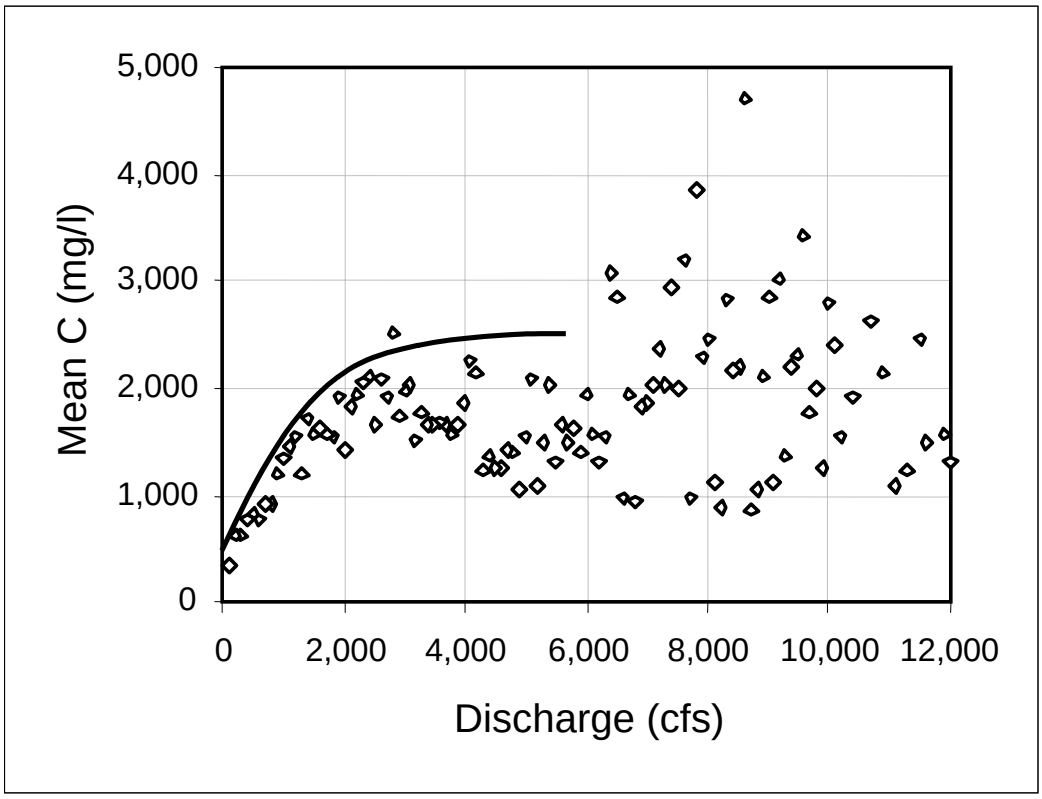
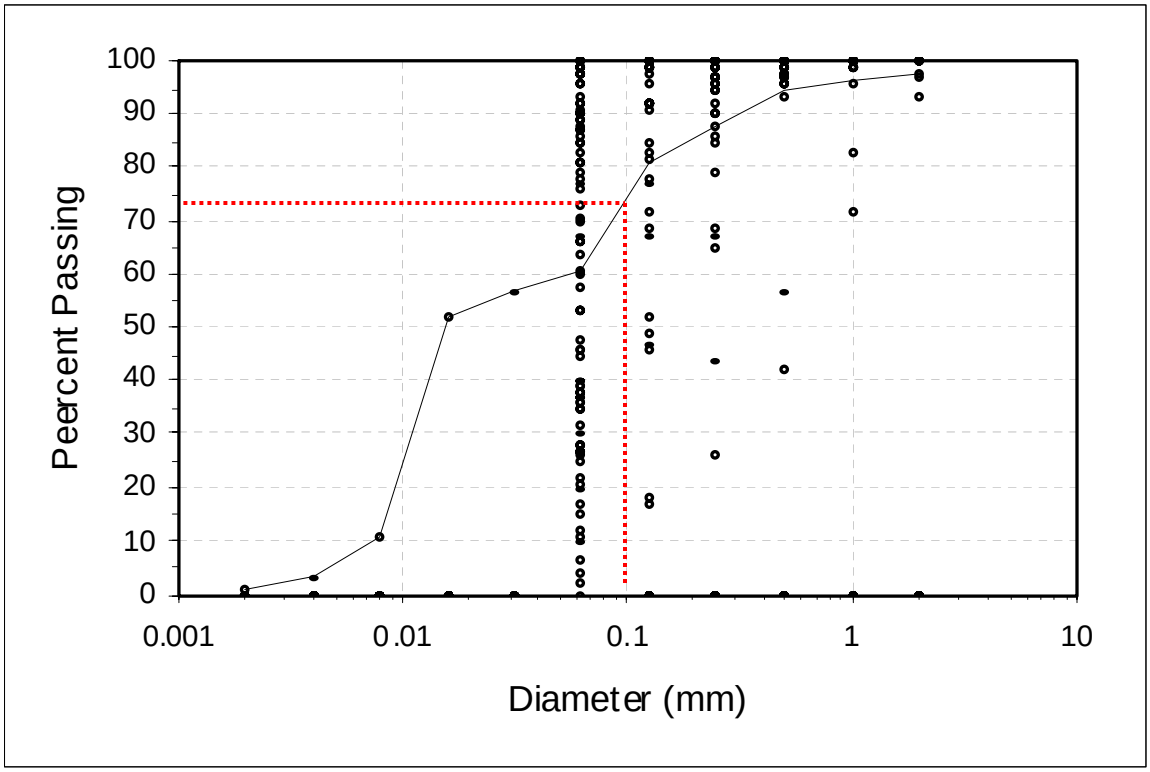


Figure A-5. Size Analysis of Suspended Sediment, Rio Grande at Otowi



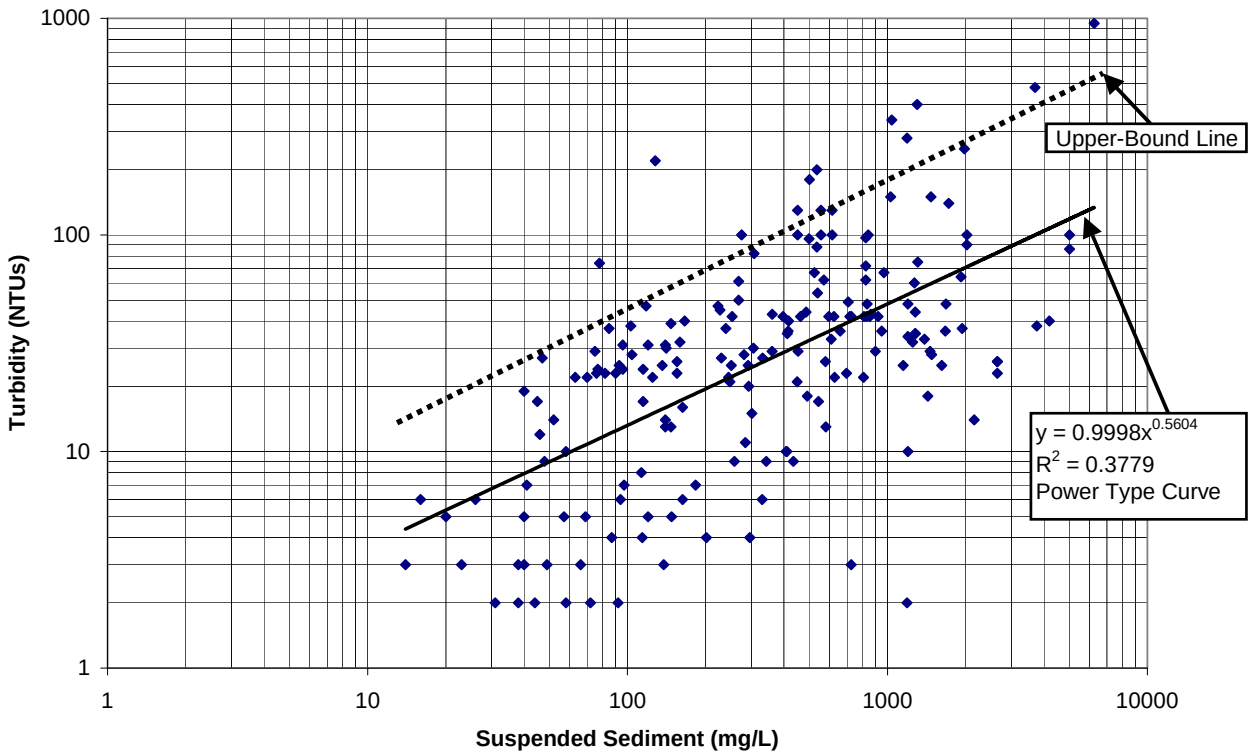


Figure A-6. Suspended Sediment Concentration versus Turbidity, Rio Grande at Otowi

Based on the relationships described above, a mass balance calculation spreadsheet was prepared to simulate the concentrations of suspended sediment in the river below the Buckman diversion, as well as in the diverted water and in the return flow (including the added sand >0.10 mm) to the river below the diversion. The mass balance equations are described in detail in CH2M HILL (February 2003b). The net effects on the Rio Grande were calculated as difference in total suspended solids (TSS) concentration and percent change in TSS concentration upstream and downstream of the diverted and returned flows.

Table 3 (in main text of the report) presents a partial summary of the calculated suspended sediment mass balances with an assumption that 30 to 40 percent of the removed sediment will be returned to the river below the intake (i.e., because of removal inefficiencies, we have assumed that a system designed to efficiently remove sediment >0.10 mm in diameter size will result in an entrapment of an additional 5 to 15 percent of the sediment load).