CHERRY CREEK BASIN MASTER PLAN

Denver Regional Council of Governments

VOLUME 3:

COSTS OF NONPOINT CONTROL OPTIONS

Richard P. Arber Associates, Inc.

May, 1985

CHERRY CREEK BASIN MASTER PLAN

CONTROL OPTION COST ANALYSIS

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COSTS OF NONPOINT CONTROL OPTIONS

I. SCOPE

The Cherry Creek Basin Master Plan will assess options for removing phosphorus from wastewater and stormwater runoff to levels that will meet adopted phosphorus standards in Cherry Creek Reservoir. The Denver Regional Council of Governments (DRCOG) and the Cherry Creek Basin Master Plan Task Force (Task Force) have identified the need to analyze costs of selected point and nonpoint source controls with the Cherry Creek Basin. Assessment and comparison of the calculated costs for each of the control options will be a major consideration in recommending alternative plans for phosphorus control in the Cherry Creek Basin. Richard P. Arber Associates was retained to estimate the costs associated with the options that were selected for analysis by the Task Force. The results of the cost analyses are presented in three volumes:

Volume 1 - Costs of Wastewater Treatment Options
Volume 2 - Costs and Water Rights Impacts of Selected Point Source Treatment Alternatives
Volume 3 - Costs of Nonpoint Control Options

The Task Force has selected four nonpoint source control alternatives in the Basin to be investigated with respect to comparative capital and operation and maintenance costs.

The major contribution of phosphorus loading to Cherry Creek Reservoir derives from nonpoint sources. The overall goal for removing phosphorus from nonpoint sources in the Cherry Creek Basin has been established at 50% (DRCOG, 1984). Processes and structures that were investigated in this study to meet this goal were rapid infiltration basins, detention basins followed by rapid infiltration, detention basins followed by sand filtration, and wetlands. With the exception of the wetlands alternative, these structures were located and sized assuming that one structure would be constructed for each sub-basin drainage into Cherry Creek. The wetlands alternative was investigated assuming one large wetlands area, located near Cherry Creek Reservoir, to serve the entire drainage basin.

Other nonpoint source control alternatives were considered by the Task Force including control of septic tank systems, erosion control practices, street sweeping, and on-site retention as well as site specific treatment structures, grassy swales, wet ponds, wetlands areas, and others. These were not included as part of this study; however, they may be incorporated to some extent into the final Master Plan based upon considerations other than costs.

The costs as presented in Volumes 1, 2 and 3 are intended only for comparative purposes to aid in the planning process. The costs are not intended to be detailed construction costs and are not to be used for budget purposes. Detailed assumptions used in the analysis of the alternatives are presented in the descriptions within this volume.

II. INTRODUCTION

Sources of phosphorus loading to a lake or reservoir include precipitation, groundwater, ambient concentrations in flows of natural water courses, stormwater or nonpoint flows, and wastewater discharges. Nonpoint sources of phosphorus have been shown to be the major phosphorus loadings for many lakes and reservoirs. In 1982, nonpoint sources contributed over 77% of the total phosphorus loading to Cherry Creek Reservoir (DRCOG, 1984). Since the nonpoint phosphorus loadings are the major phosphorus sources to Cherry Creek Reservoir, control options have been recommended for application in the Cherry Creek Drainage Basin.

Recently, nonpoint pollution has received increased national attention. This attention is due in part to the effort by the Environmental Protection Agency to better define and manage nonpoint source pollution. The results of the EPA National Urban Runoff Program (NURP) released in 1983 (USEPA, 1983) showed a concern with respect to the potential phosphorus loading from stormwater, and demonstrated that this loading could be controlled in specific areas. The NURP Report investigated a number of structures that had been constructed to control nonpoint sources of phosphorus including detention basins and recharge devices (infiltration pits, trenches, ponds, porous pavements). One observation from the NURP study was that there is a scarcity of data concerning effectiveness of removal and design criteria for nonpoint pollution control structures. In fact, a review of additional literature concerning nonpoint control structures indicates a wide range of total phosphorus removal effectiveness which appears to be site dependent. This site dependency seems to be related to such conditions as soil type, hydrology, climate and other factors. Therefore, at this time it is difficult to be precise relative to removal capabilities and design criteria for nonpoint control structures for the removal of phosphorus. However, it is possible to estimate the magnitude of removals for the purpose of general evaluations as required by this study. More detailed, site-specific evaluations may be approprite prior to final design of facilities.

III. PURPOSE

DRCOG has performed an assessment to determine the allowable annual phosphorus loading to Cherry Creek Reservoir that will meet established water quality standards. This assessment assumed that control structures will remove at least 50% of the nonpoint source phosphorus loading. In their review of the technology and effectiveness of nonpoint source control options DRCOG determined that the following alternatives should be evaluated:

- Detention basins followed by rapid infiltration.
- Rapid infiltration alone.
- Detention basins followed by sand filtration.
- Wetlands.

The purpose of the assessment described in this volume is to determine appropriate design criteria and unit costs based on available data for the phosphorus removal structures in order that capital, operation and maintenance, and equivalent annual cost for each of the alternatives can be obtained. Costs were obtained for nonpoint source treatment options as a function of increased development within the basin. These costs provide a comparison of the equivalent annual costs for each of the four alternatives.

IV. METHODOLOGY AND ASSUMED DESIGN CRITERIA

A. Methodology

Many planning alternatives exist to control the nonpoint source of phosphorus in the Cherry Creek basin. Literally thousands of scenarios are possible to meet the goal of removing at least 50% of the nonpoint source phosphorus basin wide, and each of these scenarios has its own myriad of institutional, regulatory, and operations and maintenance considerations. For this planning effort, it was determined that the nonpoint phosphorus would be removed by using a single structure for each sub-basin to treat the entire stormwater flow from each sub-basin. In this way, the complexity of institutional considerations (e.g. control of construction, operation and maintenance, performance evaluation sampling) can be minimized. In addition, in most cases this approach will be the most cost effective overall when compared to a more dispersed approach that does have advantages associated with economy-of-scale.

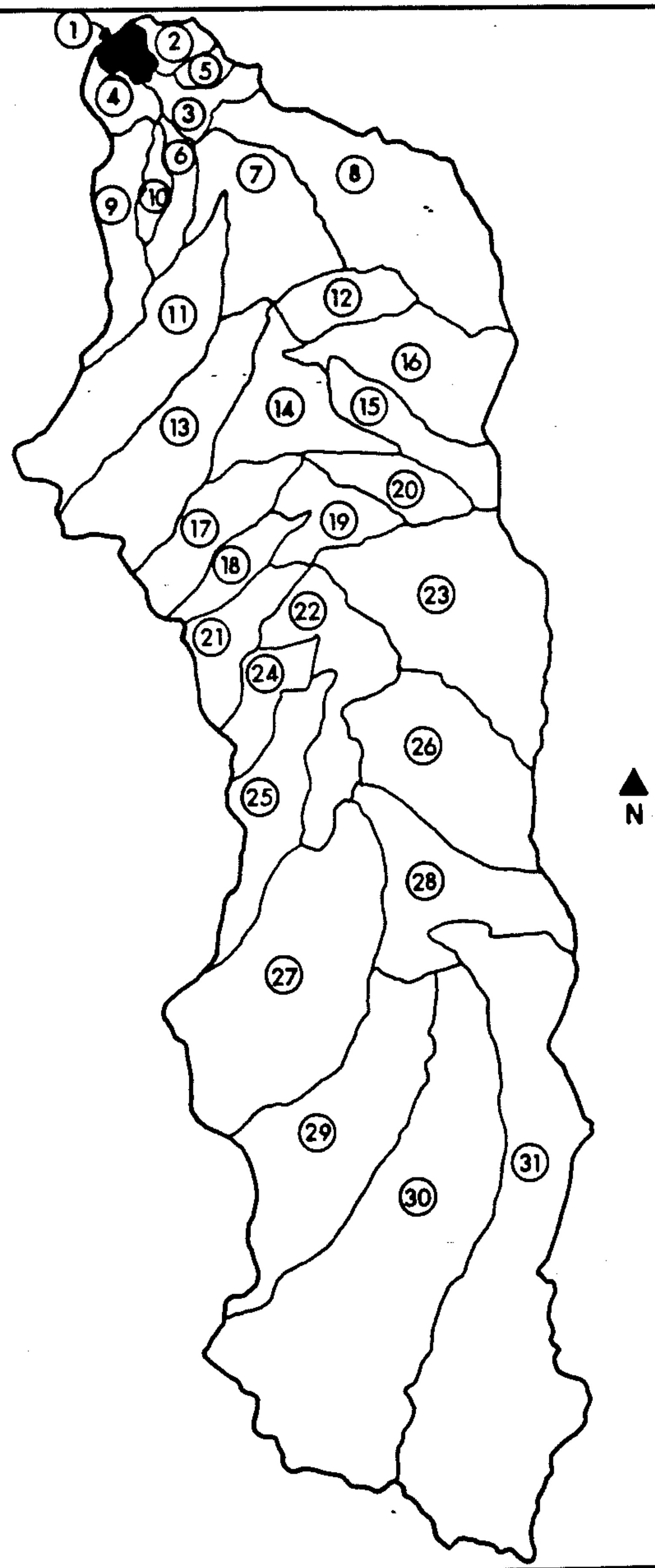
The entire Cherry Creek Drainage Basin was subdivided into 30 stormwater drainage sub-basins by DRCOG as defined by the natural topography of the basin. The location of each sub-basin is shown in Figure 1. Stormwater from each of the sub-basins was assumed to be treated by a nonpoint phosphorus removal structure located at the mouth of that sub-basin.

Regulations currently exist in the Cherry Creek Basin requiring that any increase of stormwater flow due to development be controlled to release only the historical flow downstream. Under most circumstances, this regulation requires the construction of retention structures in areas of development. The costs for these stormwater retention structures were considered to be an entirely separate cost from the costs of the nonpoint control structures and were not included in this study. However, the retention structures may remove a portion of the phosphorus in the stormwater flow.

Several additional assumptions were made for this study. Although combinations of the nonpoint control options may eventually be allowed in the basin, it was assumed that the phosphorus removal goal from nonpoint sources would be obtained by the same type of structure within each alternative (e.g., detention-rapid infiltration structures were not analyzed in combination with detention-sand filtration structures). The alternative employing wetlands as the phosphorus removal strategy assumed that there would be one large wetlands area near Cherry Creek Reservoir. No consideration was given to locating smaller wetlands areas within the basin as directed by the Task Force.

LEGEND

1. CHERRY CREEK RESERVOIR
2. DIRECT FLOW #1
3. DIRECT FLOW #2
4. DIRECT FLOW #3
5. SHOP CREEK
6. DIRECT FLOW #4
7. DIRECT FLOW #5
8. PINEY CREEK
9. COTTONWOOD GULCH
10. LONE TREE GULCH
11. HAPPY CANYON CREEK
12. BALDWIN GULCH
13. NEWLIN GULCH
14. DIRECT FLOW #6
15. TALLMAN GULCH
16. SULPHUR GULCH
17. LEMON GULCH
18. SCOTT GULCH
19. DIRECT FLOW # 7
20. KINNEY CREEK
21. McMURDO GULCH
22. DIRECT FLOW # 8
23. MOONSHINE GULCH
24. MITCHELL GULCH
25. WILLOW CREEK
26. REED HOLLOW GULCH
27. UPPER LAKE GULCH
28. DIRECT FLOW #9
29. HASKELL/ANTELOPE CREEK
30. WEST CHERRY CREEK
31. EAST CHERRY CREEK



LOCATION PLAN OF DRAINAGE SUBBASINS

Figure I

RICHARD P. ARBER ASSOCIATES, INC.
Consulting Engineering
& Project Management

All structures were sized to treat the volume of stormwater runoff resulting from the 1.5 inch and less precipitation event. Based on precipitation records, sizing the structures for the 1.5 inch storm will result in all runoff treated from 96% percent of the storm events (DRCOG, 1984). Since a major goal is to treat the first flush from all storms (Livingston, 1985), the 1-1/2 inch criteria yields a conservative approach for the purposes of this study. However, the use of a smaller storm event for design might be considered based on site specific investigations within the basin prior to design.

The volume of stormwater runoff for the sub-basins from the 1.5 inch precipitation event are shown in Table 1. These volumes were provided by DRCOG and were generated through the use of a computer model.

The required size of each of the structures was determined using the design criteria as discussed in the next section. Once a size was determined for each structure, the capital, operation and maintenance costs were determined. Standard cost curves, such as those that were appropriate for determining cost of point source removal of phosphorus, were available only for detention ponds and wetlands. Therefore, capital costs for rapid infiltration beds and sand filters had to be determined using typical unit costs for similar construction in the Colorado area. A memorandum addressing unit costs of items such as excavation, backfill, piping, gravel, etc., was developed and the unit costs were approved by the Cherry Creek Basin Master Plan Task Force. This memorandum and the unit costs that were used to determine

TABLE 1 - VOLUME OF RUNOFF ANTICIPATED FROM EACH SUB-BASIN FOR THE 1-1/2 INCH STORM EVENT

SUB-BASIN	TOTAL RUNOFF PER 1-1/2 INCH STORM EVENT (AC/FT)		
YEAR:	1990	2000	2010
Baldwin Gulch	5.4	11.9	19.9
Cottonwood Gulch	40.4	80.3	130.9
East Cherry Creek	0.0	0.0	0.0
Happy Canyon	11.2	37.2	69.6
Haskel/Antelope Creek	0.0	0.0	0.0
Kinney Creek	3.5	9.5	16.9
Lemmon Gulch	1.9	5.8	10.7
Lone Tree Creek	4.6	11.8	20.9
McMurdo Gulch	2.6	8.3	15.1
Mitchell Creek	2.1	6.7	12.4
Moonshine Gulch	5.0	13.3	23.6
Newlin Gulch	5.2	16.6	30.6
Piney Creek	6.3	12.1	19.3
Reed Creek	0.0	0.0	0.0
Scott Gulch	1.7	5.2	9.4
Shop Creek	11.6	11.9	12.2
Sulphur Gulch	4.1	9.5	16.3
Tallman Gulch	2.1	6.4	11.7
Upper Lake Gulch	0.0	0.0	0.0
West Cherry Creek	0.0	0.0	0.0
Willow Creek	0.7	2.1	3.8
Direct Flow #1	6.9	8.8	11.1
Direct Flow #2	3.7	6.2	9.3
Direct Flow #3	5.0	6.8	9.0
Direct Flow #4	6.7	21.5	40.4
Direct Flow #5	14.9	41.1	74.1
Direct Flow #6	9.0	28.7	53.0
Direct Flow #7	7.9	22.0	39.5
Direct Flow #8	2.6	8.8	16.6
Direct Flow #9	0.0	0.0	0.0
TOTAL	165.1	392.8	676.4

44/SB

the capital costs of the nonpoint source control structures is shown in Appendix A.

The costs for operating and maintaining (O&M) the nonpoint source control structures were estimated and details for determining the O & M costs are given in Appendix B. The costs for O & M for each individual structure serving each sub-basin were used to obtain total O & M costs for the individual structures in all of the alternatives except for wetlands. In the case of the wetlands, the total storm runoff for the entire basin was used and both capital and operation and maintenance costs were determined using standard cost curves (USEPA, 1980).

Equivalent annual costs for each of the control alternatives were calculated using the criteria for the equivalent annual costs of the wastewater treatment options in Volume 1: A planning period of 20 years and an interest rate of 10 percent.

B. Assumed Design Criteria

As previously discussed, there is a relative scarcity of information concerning specific removal efficiencies and design criteria for nonpoint phosphorus control structures. Following are the assumptions used in this analysis based upon literature review and personal communication with individuals who have operated nonpoint source control structures (see references). The removal efficiencies and design criteria presented here are a consensus of the information available.

Total phosphorus removal efficiencies of nonpoint source control structures have varied widely. Factors that have a substantial impact on the efficiency of a structure include the hydrology of the sub-basin, the in-situ soil character, and specific configuration of the structure, and the forms of phosphorus present. The Cherry Creek Clean Lakes Study (DRCOG, 1984) assumed the following removal efficiencies for each nonpoint treatment alternative:

Treatment Alternatives	Phosphorus Percent Removal Efficiency
Dentention ponds followed by rapid infiltration	95
Rapid infiltration	95
Detention with sand filtration	50
Wetlands	50

Based on the literature and personal communications, it appears that there is quite a range of phosphorus removal efficiencies for these treatment alternatives. It is anticipated that the nonpoint control structures considered for the Cherry Creek Basin have the potential of removing greater than 50% of the phosphorus from the stormwater flow. However, since the removal efficiencies depend upon many factors, it was decided that assuming 50% phosphorus removal for all nonpoint control alternatives was appropriate for this master planning effort. This assumption may be conservative, but site specific data does not exist to allow more definition.

Because the nonpoint phosphorus removal goal within the basin is identical to the 50% removal assumed for stormwater, this study assumed that nonpoint phosphorus control will be required for all stormwater within the basin and that treatment of a portion of this flow is not appropriate. The sub-basins that will require the nonpoint control structures are shown in Table 1. If the urbanized portion of the basin is greater than one percent of the total basin area, the sub-basin was assumed to require runoff treatment. Because monitoring by DRCOG has shown that no significant surface runoff discharges from these undeveloped sub-basins, sub-basins with less than one percent urbanization were assumed to need no runoff treatment.

Following are the specific design criteria that were used in order to size the nonpoint control structures and determine the equivalent annual costs.

Detention Basins

Detention basins were evaluated in two of the nonpoint control options: 1) preceding rapid infiltration beds, and 2) preceding sand filtration. The purposes of the detention ponds in these two alternatives is to allow for some total phosphorus and suspended solids removal by sedimentation, and to serve as flow equalization before the water is applied to the rapid infiltration or sand beds.

The detention basins were sized to detain the entire flow from the stormwater runoff derived from a 1-1/2-inch storm event within a particular sub-basin. DRCOG (1983) reported on research associated with the settling time required for effective pollutant removal in a water column. Phosphorus removal efficiencies for detention basins were on the order of 25 percent. The settling times reported ranged from 32 to 48 hours. For this study it was assumed that the volume of water captured in the detention basin would be released to the rapid infiltration or sand bed over 40 hours. This is also consistant with the criteria being considered by Douglas and Arapahoe Counties as part of their drainage criteria manuals. For design purposes, it was assumed that another storm creating significant runoff would not occur within this 40 hour period. This assumption is supported by the fact that the average time between storms for the Denver area is 144 hours (USEPA, 1984).

Rapid Infiltration

Rapid infiltration was investigated to further treat the water released from the detention basins. Rapid infiltration consists of the application of stormwater to the in-situ soils and allowing the water to seep into the groundwater. No collection system was included in the development of the alternatives, therefore, all water treated is assumed to contribute to groundwater recharge.

Sizing of the rapid infiltration beds was determined by the soil permeability at each of the sub-basin sites. The in-situ soil permeability for each of the sites was obtained from the Soil Conservation Service soil surveys of the area (U.S. Dept. of Agriculture SCS, 1974 and 1971). In many cases, several soil permeabilities were reported at the various nonpoint source control locations. The lowest soil permeability in the area was used to size the rapid infiltration bed. The use of a detention basin ahead of infiltration equalizes the runoff flows to the infiltration area. In addition, sediment is removed in the detention basin that would otherwise blind off the infiltration bed surface and result in frequent maintenance.

Sand Filtration

The stormwater was assumed to be applied to the sand bed surface at a uniform rate using a distribution piping system. A collection system was included at the bottom of the sand bed to collect the filtered water and discharge this water at the surface of a drainage way.

The sand beds were sized using the permeability of a fine sand material. The Soil Conservation Service (1974) has reported a range of permeabilities for this type of material of 6 inches per day to 20 inches per day. A permeability of 10 inches per day was assumed in determining the required area of the sand beds for each of the sites in each sub-basin. It is anticipated that the actual filtration rate through a sand bed will be greater than the permeability since a free draining condition will exist with the use of underdrains. Sand column pilot testing may be appropriate to determine proper loading rates and anticipated phosphorus removal efficiencies.

Wetlands

The wetlands site was assumed to be located just upstream of the Cherry Creek Reservoir presumably on land owned by the Corps of Engineers. For the purpose of this study, the wetlands area was sized based on a 5-day detention time for the stormwater flow from the entire Cherry Creek Basin resulting from a single 1-1/2 inch storm event. Based on existing wetlands areas, this criteria is probably not as conservative as criteria used for the other nonpoint treatment alternatives to attain the goal of 50 percent phosphorus removal.

IV. COST RESULTS

The design criteria outlined above were used to size the individual nonpoint source control structures for each option. The size of each structure was then related to capital and operation and maintenance costs. Equivalent annual costs were developed based on a 20-year service life, a 10% money interest rate, and disregarding inflation.

Tables 2 through 5 show the land requirements, capital costs, O & M costs, and equivalent annual costs to remove 50% of the nonpoint source phosphorus from the anticipated runoff produced by a 1-1/2 inch storm event basin wide in the year 2010. Land requirements and costs are shown for each sub-basin for each alternative investigated.

These tables represent the costs associated with the nonpoint source control structures required to treat the runoff anticipated in the

TABLE 2
LAND AREA REQUIREMENTS AND COSTS FOR DETENTION POND AND RAPID INFILTRATION FOR THE YEAR 2010

SUBBASIN	LAND REQUIRED	TOTAL CAPITAL COST*	TOTAL O.& M. COST	TOTAL EQUIVALENT ANNUAL COST
	(ACRES)	(1985$)	(1985$)	
BALDWIN GULCH	101.7	1181000	37000	248000
COTTONWOOD GULCH	218.7	2545000	45000	433000
EAST CHERRY CREEK	0.0	0	0	0
HAPPY CANYON	116.3	1394000	39000	279000
HASKEL/ANTELOPE CREEK	0.0	0	0	0
KINNEY CREEK	28.7	391000	30000	135000
LEMMON GULCH	18.2	262000	28000	113000
LONE TREE GULCH	35.5	471000	31000	147000
MCMURDO GULCH	25.6	353000	29000	129000
MITCHELL GULCH	63.4	757000	34000	189000
MOONSHINE GULCH	120.6	1391000	39000	278000
NEWLIN GULCH	52.0	664000	33000	177000
PINEY CREEK	32.8	440000	30000	142000
REED HOLLOW	0.0	0	0	0
SCOTT GULCH	16.0	236000	28000	110000
SHOP CREEK	7.5	150000	25000	91000
SULPHUR GULCH	10.0	183000	26000	98000
TALLMAN GULCH	19.9	286000	28000	118000
UPPERLAKE GULCH	0.0	0	0	0
WEST CHERRY CREEK	0.0	0	0	0
WILLOW CREEK	6.5	107000	25000	86000
DIRECT FLOW #1	18.9	272000	28000	116000
DIRECT FLOW #2	15.8	233000	28000	109000
DIRECT FLOW #3	15.3	226000	27000	107000
DIRECT FLOW #4	67.5	840000	34000	201000
DIRECT FLOW #5	123.8	1482000	39000	290000
DIRECT FLOW #6	88.5	1081000	37000	236000
DIRECT FLOW #7	200.8	2259000	43000	394000
DIRECT FLOW #8	10.1	186000	26000	99000
DIRECT FLOW #9	0.0	0	0	0
TOTAL	1413.8	17390000	769000	4325000

* Including costs for land at $8500/acre

TABLE 3
LAND AREA REQUIREMENTS AND COSTS FOR
RAPID INFILTRATION ALONE FOR THE YEAR 2010

SUBBASIN	LAND REQUIRED	TOTAL CAPITAL COST *	TOTAL O.& M. COST	TOTAL EQUIVALENT ANNUAL COST
	(ACRES)	(1985$)	(1985$)	
BALDWIN GULCH	99.5	1081000	36000	234000
COTTONWOOD GULCH	207.8	2234000	43000	388000
EAST CHERRY CREEK	0.0	0	0	0
HAPPY CANYON	110.5	1198000	37000	250000
HASKEL/ANTELOPE CREEK	0.0	0	0	0
KINNEY CREEK	26.8	301000	29000	121000
LEMMON GULCH	17.0	193000	27000	103000
LONE TREE GULCH	33.2	369000	30000	132000
MCMURDO GULCH	24.0	270000	29000	116000
MITCHELL GULCH	62.0	679000	33000	177000
MOONSHINE GULCH	118.0	1278000	38000	261000
NEWLIN GULCH	48.6	536000	32000	158000
PINEY CREEK	30.6	342000	30000	128000
REED HOLLOW	0.0	0	0	0
SCOTT GULCH	14.9	171000	27000	100000
SHOP CREEK	6.1	73000	24000	80000
SULPHUR GULCH	8.1	96000	25000	85000
TALLMAN GULCH	18.6	211000	28000	106000
UPPERLAKE GULCH	0.0	0	0	0
WEST CHERRY CREEK	0.0	0	0	0
WILLOW CREEK	6.0	72000	24000	80000
DIRECT FLOW #1	17.6	200000	28000	105000
DIRECT FLOW #2	14.8	169000	27000	99000
DIRECT FLOW #3	14.3	164000	27000	98000
DIRECT FLOW #4	64.1	703000	33000	180000
DIRECT FLOW #5	117.6	1274000	37000	259000
DIRECT FLOW #6	84.1	917000	35000	211000
DIRECT FLOW #7	197.5	2125000	42000	374000
DIRECT FLOW #8	8.3	98000	25000	85000
DIRECT FLOW #9	0.0	0	0	0
TOTAL	1350.0	14754000	746000	3930000

* Including costs for land at $8500/acre

TABLE 4
LAND AREA REQUIREMENTS AND COSTS FOR DETENTION POND AND SAND FILTRATION FOR THE YEAR 2010

SUBBASIN	LAND REQUIRED	TOTAL CAPITAL COST*	TOTAL O.& M. COST	TOTAL EQUIVALENT ANNUAL COST
	(ACRES)	(1985$)	(1985$)	
BALDWIN GULCH	2.8	204000	34000	126000
COTTONWOOD GULCH	14.8	973000	56000	279000
EAST CHERRY CREEK	0.0	0	0	0
HAPPY CANYON	7.9	558000	47000	205000
HASKEL/ANTELOPE CREEK	0.0	0	0	0
KINNEY CREEK	2.4	179000	32000	116000
LEMMON GULCH	1.5	126000	28000	97000
LONE TREE GULCH	2.9	211000	35000	129000
MCMURDO GULCH	2.1	164000	31000	111000
MITCHELL GULCH	1.8	144000	29000	102000
MOONSHINE GULCH	3.3	235000	35000	132000
NEWLIN GULCH	4.3	288000	38000	147000
PINEY CREEK	2.7	198000	34000	124000
REED HOLLOW	0.0	0	0	0
SCOTT GULCH	1.3	115000	27000	93000
SHOP CREEK	1.7	142000	29000	102000
SULPHUR GULCH	2.3	173000	32000	115000
TALLMAN GULCH	1.7	137000	18000	71000
UPPERLAKE GULCH	0.0	0	0	0
WEST CHERRY CREEK	0.0	0	0	0
WILLOW CREEK	0.5	55000	21000	68000
DIRECT FLOW #1	1.6	130000	28000	98000
DIRECT FLOW #2	1.3	113000	26000	91000
DIRECT FLOW #3	1.3	111000	26000	89000
DIRECT FLOW #4	4.6	345000	40000	161000
DIRECT FLOW #5	8.4	582000	48000	211000
DIRECT FLOW #6	6.0	436000	44000	181000
DIRECT FLOW #7	4.5	339000	40000	160000
DIRECT FLOW #8	2.3	176000	32000	115000
DIRECT FLOW #9	0.0	0	0	0
TOTAL	84.1	6134000	810000	3123000

* Including costs for land at $8500/acre

TABLE 5
LAND AREA REQUIREMENTS FOR COSTS AND WETLANDS
FOR THE YEAR 2010

SUBBASIN	LAND REQUIRED	TOTAL CAPITAL COST *	TOTAL O.& M. COST	TOTAL EQUIVALENT ANNUAL COST
	(ACRES)	(1985$)	(1985$)	
TOTAL	169.1	7766000	1283000	4709000

* Including costs for land at $8500/acre

year 2010. Land requirements and costs are shown for each sub-basin for each alternative investigated.

These tables represent the costs associated with the nonpoint source control structures required to treat the runoff anticipated in the year 2010. Therefore, these results reflect the total committment required for the year 2010 for phosphorus removal from nonpoint sources in the basin.

Table 6 shows the comparative total equivalent annual costs of the four nonpoint control alternatives investigated in this study. Based upon the analysis of the equivalent annual cost, it appears that by the year 2010 the detention basin/sand filtration combination is the most cost effective.

TABLE 6

TOTAL BASINWIDE COSTS OF NONPOINT CONTROL IN 2010
TOTAL EQUIVALENT ANNUAL COSTS*

Treatment Alternative	Equivalent Annual Costs
Detention/ Sand Filtration	$3,123,000
Rapid Infiltration	$3,930,000
Detention/ Rapid Infiltration	$4,325,000
Wetlands	$4,708,000

* Costs shown are total projected costs to treat stormwater runoff from the 1-1/2 inch storm event for the indicated year.

Costs for 2010 were based on an annual basis per pound of phosphorus removed are presented in Table 7.

TABLE 7

COSTS OF NONPOINT CONTROL PER POUND OF PHOSPHORUS REMOVED IN 2010*

Treatment Alternative	$/LB Assuming 50% removal of P	$/LB Assuming 95% removal of P
Detention/ Sand Filtration	142	75
Rapid Infiltration	179	94
Detention/ Rapid Infiltration	197	104
Wetlands	214	113

* Assuming 43,900 pounds of phosphorus per year in stormwater runoff

These costs are comparable to unit costs experienced for nonpoint source control at Dillon Reservoir. A range of annual costs of $67 to $134 per pound of phosphorus removed at Dillon were reported (AWWA, 1985 and Elmore, 1984).

V. DISCUSSION

The cost data derived in the study indicate that by the year 2010 the most cost effective nonpoint source control options on a basin-wide basis are:

1. Detention basins followed by sand filtration
2. Rapid infiltration alone
3. Detention basins followed by rapid infiltration
4. Wetlands

Application of a combination of the nonpoint source controls as shown above was not performed in detail in this study; however, inspection of Tables 2 through 4 show that the soil permeabilities at several of the sub-basin sites will allow rapid infiltration to be used and this may be the most cost effective treatment for that particular sub-basin. Based on the preliminary soil survey that was performed in the study, the sub-basins that demonstrate permeabilities at the mouth of each drainage area that may be appropriate for the rapid infiltration option are Shop Creek, Sulphur Gulch, and Direct Flow #8. Therefore, the most cost-effective solution for nonpoint source control within the basin might be a combination of detention basins and sand filtration for most of the sub-basins and rapid infiltration for Shop Creek, Sulphur Gulch and Direct Flow #8. Such an approach can be considered in further detail during the design stage of facilities for these sub-basins.

The costs shown in the Tables and Figures in this study should be used for comparison of the alternatives and only as a general representation of the actual costs for constructing and operating the structures. As previously discussed, the costs of the various alternatives are sensitive to factors such as soil type, hydrology, climate and other factors. The actual removal efficiency for each structure also depends on the operation and maintenance.

The wetlands control option would consist of 169 acres of wetlands area within the Cherry Creek Reservoir Recreation Area. Of the nonpoint control options considered in this study, the wetlands option is the most questionable with respect the effectiveness of phosphorus removal in this climate. A wetlands relies greatly on the plant uptake of the phosphorus in the stormwater, unlike the other control structures that rely on filtration, adsorption, microbiological degradation, mineralization, etc. The percentage of phosphorus that is taken up by the plants within a wetlands area is a function of plant type and the climate required to maintain the plant growth is a very important consideration. Since the climate has extreme variations in the Cherry Creek Basin, the reliability of removing phosphorous from the nonpoint sources is less certain. Harvesting of the plants in the area is required and is expected to be a major maintenance consideration.

In addition, wetlands removal efficiencies are subject to peak flows. Therefore, they may be appropriate for nutrient removal in wastewater effluent since flows are comparatively constant; however, single storm events could reduce the effectiveness of the wetlands treatment.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. The cost analysis performed in this study show that to treat the runoff flow anticipated in the year 2010, the order of cost effectiveness for nonpoint source control options applied basin wide is:

1. Detention followed by sand filtration
2. Rapid Infiltration alone
3. Detention followed by rapid infiltration
4. Wetlands

B. The use of the 1.5 inch precipitation event as a design criteria for the nonpoint source treatment structures should be investigated. There is evidence from other drainage basins that the "first flush" runoff from storm events contribute most of the phosphorus in runoff. Monitoring of runoff in the Cherry Creek Basin should be performed to establish the appropriate design criteria applicable to the basin.

C. Pilot testing should be performed using sand columns to determine the range of nonpoint phosphorus removal efficiencies in the Cherry Creek Basin. This may allow a greater amount of phosphorus to be allocated by demonstrating that phosphorus removals of greater than 50 percent are attainable.

D. Other nonpoint phosphorus control alternatives should be considered for use in the Cherry Creek Basin in addition to the nonpoint control alternatives focused upon in this study.

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Personal Communication

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APPENDIX A

UNIT COSTS FOR NONPOINT CONTROL STRUCTURES

Table 2

UNIT COSTS FOR NONPOINT CONTROL OPTIONS

Cost Item	Units	Cost($)/Unit
Excavation	cu yd	$1-large, $2-small
Backfill and compaction	cu yd	3
Sand and gravel	cu yd	14
Rip-rap	sq yd	35
Site clearing	acre	2,000
Open channel (unlined-lined)	lineal foot (l.f.)	5-13*
Culverts (6"-60")**	dia.	2/inch-foot
Storm sewer, concrete (12"-60")**	dia.	2/inch-foot
Liner for ponds (clay)	sq ft	0.75
Concrete structures/headwalls	each	1,200-5,000*
Land***	acre	8,500
Seeding	m. sq ft	20-30*
Monitoring wells	ft	updated cost curves from ref. 1
Fencing, service roads	acres	updated cost curves from ref. 1
Administration, laboratory testing****	cfs	updated cost curves from ref. 1

* Range due to anticipated variation in size

** Trenching, bedding, backfill cost are included in the culvert and storm sewer cost

*** Land cost of $8,500 per acre reflects the cost of agricultural land. If structure is paced in residential land, cost should be increased by $31,500/acre, commercial land should be increased by $122,800/acre.

**** Administration and laboratory may be coupled with point source operations.

APPENDIX B

OPERATION AND MAINTENANCE CONSIDERATIONS

OPERATION AND MAINTENANCE CONSIDERATIONS

1. Detention Basins

   Operation and maintenance requirements
   - o Maintenance of dike
   - o Weed control

   O & M costs developed from Reference USEPA, 1979

2. Rapid Infiltration (RI)

   Operation and Maintenance requirements and costs versus size of bed

Item	O & M Costs Per Bed Per Year — Area of RI Bed (FT^2)			
	10,000	100,000	1,000,000	10,000,000
Scarify Bed 4 times/year	$ 4000	$ 7000	$ 9000	$18000
Weed Control	2000	3000	5000	6000
General Maintenance & Inspection	2000	2000	2000	2000
Sampling	1000	1000	1000	1000
Analysis & Lab	1000	1000	1000	1000
Subtotal	$10,000	$14,000	$18,000	$28,000
Contingencies @ 25%	3000	4000	5000	7000
Subtotal	$13,000	$18,000	$23,000	$35,000
Administration @ 15%	2000	3000	3000	4000
	$15,000	$21,000	$26,000	$40,000
Materials @ 10%	2000	2000	3000	4000
TOTAL	$17,000	$23,000	$29,000	$44,000

3. Sand Filters

   Operation and Maintenance requirements and costs versus size of bed.

O & M Costs
Per Bed Per Year

Item	Area of Filter (FT^2)				
	1,000	1,000	25,000	50,000	175,000
Scarify Bed 4 times/year	$ 2000	$ 4000	$ 6000	$ 7000	$ 11000
Relace Top Layer of Sand 1 time/year	3000	5000	8000	9000	11000
Weed Control	1000	1000	2000	2000	3000
General Maintenance & Inspection	2000	3000	4000	4000	6000
Sampling	1000	1000	1000	1000	1000
Analysis & Lab	1000	1000	1000	1000	1000
Subtotal	$10,000	$15,000	$21,000	$24,000	$34,000
Contingencies 25%	3,000	4,000	5,000	6,000	9,000
Subtotal	$13,000	$19,000	$26,000	$30,000	$43,000
Administration 15%	2,000	3,000	4,000	5,000	6,000
Subtotal	$15,000	$22,000	$30,000	$35,000	$49,000
Materials 10%	2,000	2,000	3,000	4,000	5,000
TOTAL	$17,000	$24,000	$33,000	$39,000	$54,000

4. Wetlands

Operation and maintenance requirements

- o Weed control
- o General maintenance and inspection

O & M Costs developed from Reference USEPA, 1980.

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