PUNISHED WOMAN'S LAKE
DIAGNOSTIC FEASIBILITY STUDY REPORT

Prepared
by
Richard A. Hanson

OFFICE OF WATER RESOURCES MANAGEMENT
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
APRIL, 1991

PUNISHED WOMAN'S LAKE
DIAGNOSTIC FEASIBILITY STUDY REPORT

Prepared
by
Richard A. Hanson

OFFICE OF WATER RESOURCES MANAGEMENT
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
APRIL, 1991

ACKNOWLEDGEMENTS

The author wishes to thank those who contributed to the completion of the Punished Woman's Lake Diagnostic/Feasibility Study Report. Keith DeLange was especially helpful in plotting the survey points for the sediment and water depth contour maps. Dr. Wayne C. Houtcooper provided much information describing the lake and its watershed and Andrew Repsys performed the AGNPS modeling and their efforts are appreciated.

A special thank you goes to the Department's Office of Information Services for their typing of the rough and final drafts of this report.

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

Punished Woman's Lake is a 193 hectare (477 acre) lake located in Codington County, South Dakota. Pondweed, a submerged aquatic plant, has proliferated to the extent that recreational uses such as boating, fishing and water sports have been impacted. This problem is a response to the siltation caused shallowness of the lake which in turn favors weed growth. Shoreline erosion and bank sloughing also contribute to the siltation.

In 1988 the Punished Woman's Lake Association and the South Dakota Department of Environment and Natural Resources began a diagnostic/feasibility study of the lake. A water quality monitoring program was initiated with local citizens providing the manpower for water quality sampling. Lake sediments were collected and analyzed for chemical content and a sediment survey was conducted to determine sediment depth and volume. The Agricultural Nonpoint Source Pollution Model (AGNPS) was used to assess the impact of feedlots on sediment and nutrient inputs to the lake and to provide a basis to prioritize areas in the watershed for possible implementation of nonpoint source control measures.

The study indicated that the lake has poor water quality, especially with respect to water clarity although nutrient levels are also excessive. Calculations based on the sediment survey estimated .002 cubic kilometers (2,731,000 cubic yards) of sediment in the lake. No toxic substances were found in the sediments in appreciable amounts. Possible sources of sediment and nutrients include watershed inputs, especially from a number of areas identified with the AGNPS model, and from shoreline bank erosion.

Restoration techniques for macrophyte control were reviewed and included: water level drawdown, shading and sediment covers, biological controls, harvesting, herbicides, sediment removal, and land use controls. Because of various constraints water level drawdown, shading, and biological control were not considered viable restoration alternatives. Sediment covers pose too many logistical problems for whole-lake use but they can be an effective long-term solution for clearing small areas near the shoreline. Harvesting was not considered as an effective control for large areas because the process is relatively slow but using a harvester in small areas is feasible. Herbicides were not considered a viable long-term solution but they may be useful on a spot-check basis in small areas. Sediment removal and lake deepening was considered the most effective means for long-term control of submerged macrophytes although the costs are relatively high. Whole lake dredging may not be economical and sediment removal in deeper areas combined with one of the techniques appropriate for smaller near-shore areas should be considered. Land use controls should also be implemented in an effort to curb further siltation and nutrient loading to the lake.

NOTE: The South Dakota Department of Water and Natural Resources (SDDWNR) officially changed its name on April 14, 1991 to the South Dakota Department of Environment and Natural Resources (SDDENR). All references to SDDWNR in this document have been changed to SDDENR.

INTRODUCTION

Punished Woman's Lake is a 193 hectare (477 acre) lake located in Codington County of South Dakota. The lake is used for recreation, primarily fishing and swimming, and is an important natural resource for those residing in the area. The lake, however, has been over-run with pondweed (Potmogeton spp.) to the extent that swimming, boating, and fishing are impaired. Shoreline bank erosion is also a serious problem.

In 1985 the Punished Woman's Lake Committee contacted the South Dakota Department of Environment and Natural Resources (SDDENR) for assistance to assess the situation, recommend problem solutions, and eventually implement those solutions. It was subsequently decided by the Punished Woman's Lake Association and SDDENR to begin a study to assess the problems and recommend potential solutions. A comprehensive diagnostic/feasibility study was initiated in 1988 and included an evaluation of lake and tributary water quality, lake sediment amount and distribution, and watershed use and critical area designation.

The study was a cooperative effort with the Punished Woman's Lake Association collecting water samples and watershed land use information and the State providing water quality analyses, technical assistance, water sample collection training, and data compilation and analysis.

PROJECT AREA DESCRIPTION

Punished Woman's Lake is an oval shaped lake located in Codington County and is considered part of the Coteau des Prairie region of South Dakota (Figure 1). The lake is State owned and is a popular recreation area for fishing and swimming. The estimated population within a 40.4 kilometer (65 mile) radius of the lake is 103,135.

The lake covers 193 hectares (477 acres) with an average depth of 1.65 meters (5.4 feet) and a maximum depth of 2.44 meters (8.0 feet). Thermal stratification does not occur and the lake is well mixed by wind action. Approximately 10% of the shoreline is covered with cattail (Typha latifolia) and bullrush (Scirpus spp.) and 80-75% of the lake contains pondweed (Potamogeton spp.). The lake has been assigned the following beneficial uses by the State of South Dakota (also see Table 1):

- Warm water semipermanent fish life propagation;
- Immersion recreation;
- Limited contact recreation; and
- Wildlife propagation and stock watering.

The Punished Woman's lake watershed is comprised of 4,824 hectares (12,280 acres) of generally hilly terrain. The soils are well drained and the lake is thought to have an extensive connection with the underlying aquifer (State Lakes Preservation Committee,

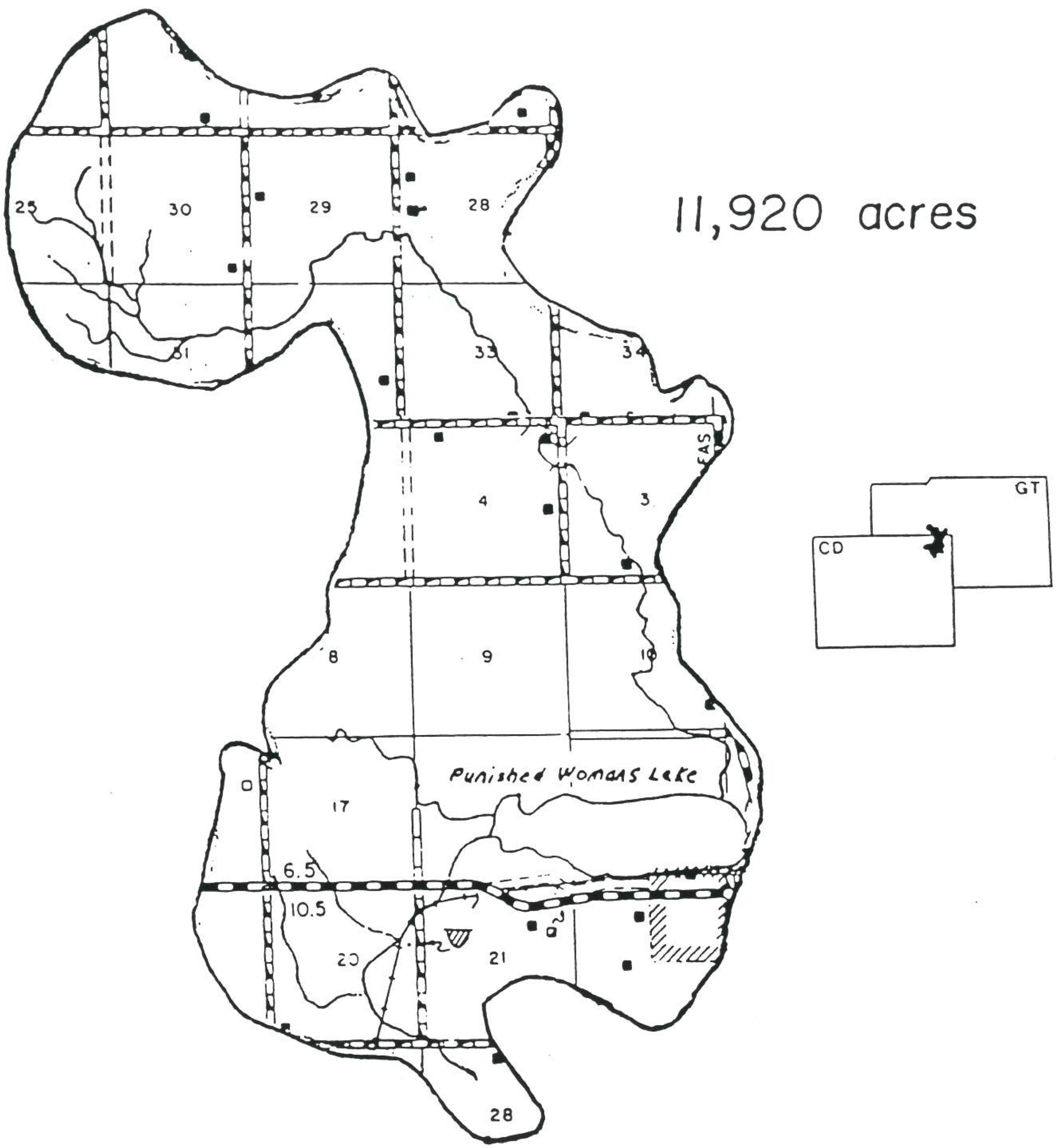

Figure 1. General location of Punished Woman's Lake

Table 1. South Dakota Surface Water Quality Standards for Punished Woman's Lake.

Parameter	Standard (24 hour composite sample)	1.75 variation allowed for grab samples
Water temperature	90°F (32.2°C)	-
Dissolved oxygen	5.0 mg/l	-
pH	6.3 - 9.0 units	-
Conductivity	4000 umhos/cm at 25°C	7000 umhos/cm at 25°C
Total alkalinity	750 mg $CaCO_3$/l	1312.5 mg/$CaCO_3$/l
Dissolved solids	2500 mg/l	4375 mg/l
Suspended solids	90 mg/l	157.5 mg/l
Nitrate	50 mg/l	87.5 mg/l
Un-ionized ammonia	.04 mg/l	.07 mg/l
Fecal coliform	200/100 ml*	-

* Based on a minimum of 5 samples obtained during separate 24-hour periods for any 30-day period. For any one sample collected from May 1 to September 30, the criterion is 400/10 ml.

NOTE: Other parameters apply to the lake but were not analyzed--these include total residual chlorine, total cyanide, free cyanide, hydrogen sulfide, PCBs, and sodium absorption ratio.

1977). Soil types consist of 32% Buse, 32% Renshaw - Fordville, 26% Vienna - Lismore, and 11% Forman - Aastad - Buse. Land use in the watershed is predominately rangeland (72%) and cropland (28%).

Two major tributaries enter the lake, at the southwest and northeast ends, and five smaller intermittent streams enter the lake at various locations. Water inflows are generally limited to times of run-off associated with snowmelt or rainstrom events. The lake outlet is located at the east end of the lake.

PREVIOUS STUDIES

Two previous water quality surveys have been completed on Punished Woman's Lake. The lake was included as part of a survey of lakes in the Coteau des Prairie (State Lakes Preservation Committee, 1977) and as part of a statewide survey conducted by the State of South Dakota (Koth, 1981).

The first study found the lake to have excellent water quality and the lake was ranked second best out of 236 lakes surveyed. Although excessive emergent vegetation was noted, it was considered an asset because the vegetation provided game fish habitat and a degree of nuisance algae control by utilizing nutrients that would otherwise be used by algae. Control of sediment input by construction of a sediment basin was recommended as a technique to restrict sediment input.

The second survey also reported excellent water quality with relatively low nutrient concentrations (mean concentrations of total phosphorus and orthophosphate of .032 mg/l and .007 mg/l respectively). Shoreline bank erosion was estimated to be moderate. Aquatic vascular plants such as pondweed were reported as impairing recreational uses and sedimentation was perceived to be a potential problem in the future.

METHODS AND MATERIALS

Tributary Sample Collection

The purpose of the tributary monitoring program was to collect the water quality and flow data required to develop both nutrient and hydraulic budgets for the lake. These budgets can be used to determine the total loadings from various sources and allow efficient targeting of areas for pollution control.

The outlet and the two major tributaries were selected as tributary sample sites and descriptions of each are as follows (also see Figure 2).

Site 1. Outlet, located at the east end of the lake. Lat. 45° 6' 43" Long. 96° 55' 9"

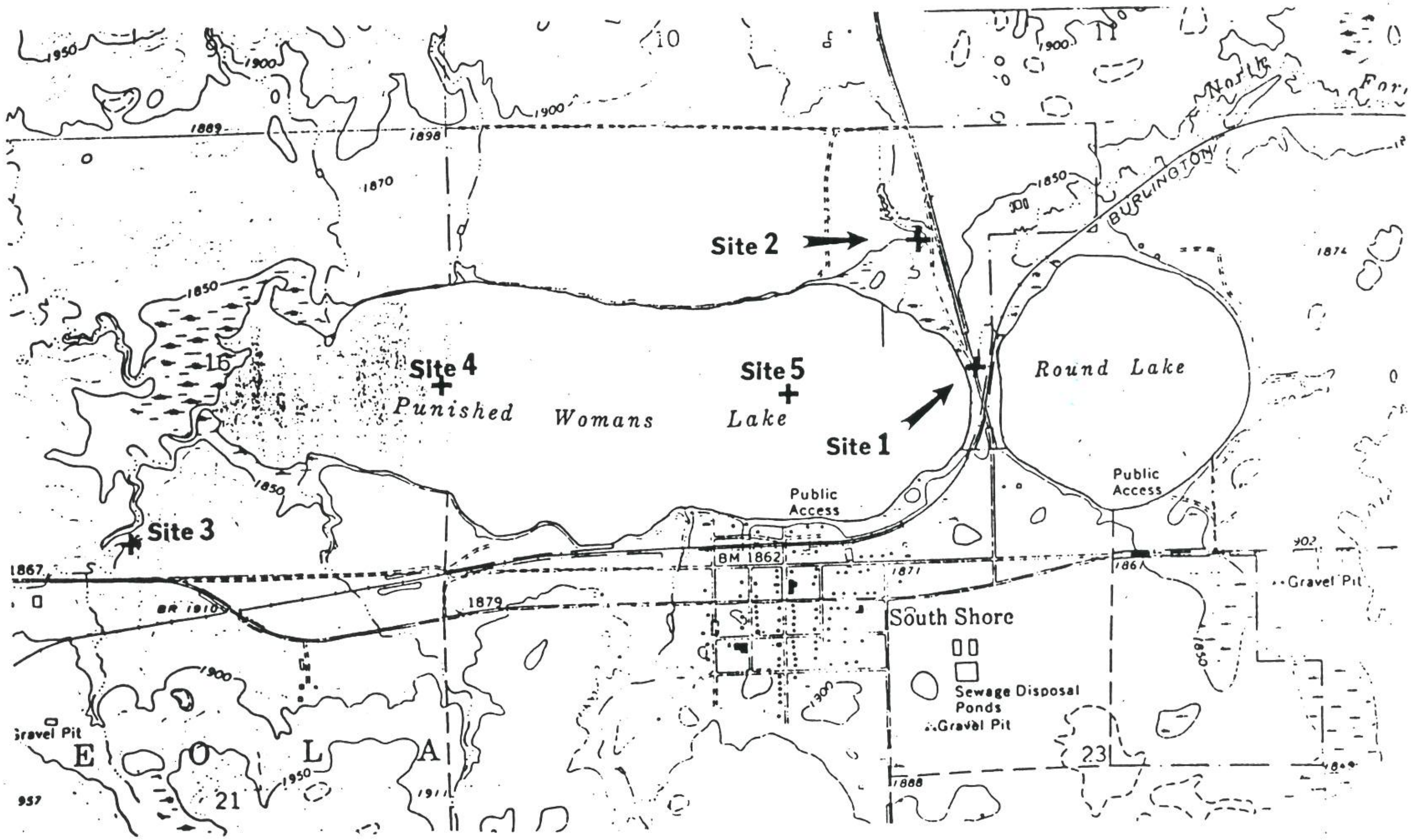

Figure 2. Punished Woman's Lake sampling sites.

Site 2. Northeast Tributary, draining Antelope Valley and flowing through Punished Woman's Lake State Public Shooting Area before entering the lake. Lat. 45° 7' 03" Long. 96° 55' 18"

Site 3. Southwest Tributary, draining all or portions of Section 16, 17, 18, 19, 20, 21, 28, T119N, R51W. Lat. 45° 6' 29" Long. 96° 55' 18"

Since the tributaries were intermittent, sampling was limited to times of water flow whenever possible. The Diagnostic/Feasibility study plan (SDDENR, 1988) called for these sites to be sampled three times during the first week of snowmelt runoff and twice weekly thereafter until runoff stops. The plan also called for sampling during two rainstorm events.

Each site was surveyed by personnel from the SDDENR Division of Water Resources Management for cross-sectional area and a Leopold-Stevens Model 68 stage recorder was placed at each site to continuously record water levels. Maintenance of the recorders was the responsibility of the local sponsor.

Water samples were collected in mid-stream by the grab sample method. The samples were placed on ice and transported to the South Dakota State Health Laboratory for analysis. The samples were analyzed for the parameters listed in Table 2. Field parameters were measured during each sampling event and included water and air temperature, pH, and stream depth and width. General visual observations were also recorded. Brief discussions on the purpose of monitoring each parameter are given in Appendix A.

In-lake Sample Collection

Water samples were collected from the lake for the purpose of characterizing the existing chemical and biological status of the lake and determining tropic state indices and use impairments. These data can also be used for comparative purposes after implementation activities have occurred.

Two sampling sites in the lake were selected (Figure 2.)

Site 4. West inlake site, located midway on section line between sections 15 and 16, T119N, R51W. Lat. 45° 6' 47" Long. 96° 56' 35"

Site 5. East inlake site, located midway on section lines between sections 14 and 15, T119N, R51W. Lat. 45° 6' 47" Long. 96° 55' 43"

Each site was sampled monthly from October through March and twice a month from April through September. Water samples were taken from the water surface and from one foot above the lake bottom with a Van Dorn sampler. The samples were placed on

Table 2. Methods and References for physical and chemical parameters.

Parameter	Method	Reference
Temperature	Themometric	APHA (1985)
Secchi disc*	Shaded side of boat	Lind (1974)
Dissolved oxygen	Azide modification of Winkler	APHA (1985)
pH	pH probe, electronetric	APHA (1985)
Total alkalinity	Potentiometric	EPA (1983)
Ammonia-N	Automated phenate	EPA (1983)
Kjeldahl-N	Semi-automated block digester, colorimetric	APHA (1985)
Orthophosphate-P	Ascorbic acid	EPA (1983)
Total phosphorus	Persulfate digestion, ascorbic acid reduction	EPA (1983)
Total solids	Gravimetric (103-105° C)	EPA (1983)
Total suspended solids	Gravimetric (103-105° C)	EPA (1983)
Total dissolved solids	Gravimetric (180° C)	EPA (1983)
Fecal coliforms	Membrane filter	APHA (1985)
Conductivity*	Conductivity probe, Wheatstone bridge	EPA (1983)

* In-lake samples only.

ice and transported to the South Dakota State Health Laboratory for analysis. The samples were analyzed for the parameters listed in Table 2. Parameters measured in the field include water and air temperatures, pH, Secchi disk, dissolved oxygen, ice cover, water depth, and water color. General visual observations were also noted. Water samples were also retained for algal identification and enumeration.

Lake Sediment Assessment

Sediment and overburden water samples were collected from two mid-lake sites for elutriate tests (Figure 2). The samples were analyzed by the U.S. Army Corps of Engineers (COE) under a Section 22 Agreement with the State of South Dakota. The analytical methodologies can be obtained from COE upon request. These data can be used to determine the chemical content of the sediment and their potential effect upon the lake water if stirred by dredging activities. Hazardous substances may also be detected and the analyses will permit an assessment of the suitability of using the sediments for crop production.

In addition, a sediment survey was conducted by SDDENR with assistance from local citizens during the winter of 1987/1988. The depth of soft sediment was determined by probing with rebar at surveyed points on the lake. Water depth and sediment depth contour maps were created from these data.

Land Use/Feedlot Data Collection and Assessment

The collection of land use data is to determine those areas and/or feedlots that present the most severe problems in terms of erosion, nutrient loss, and water quality degradation. The Agricultural Non-Point Source Pollution Model (AGNPS), developed by Young et al. (1987), was used to prioritize areas of greatest concern. The model used 21 parameters, many of which were collected by local citizens through on-site visits to farmsteads. A detailed user guide for the AGNPS model can be obtained from SDDENR upon request.

RESULTS AND DISCUSSION

All water quality data generated during the study were compiled and tabulated by SDDENR and are included in Appendix B. Water flow data, however, were lacking because of a "dry" water year and the lack of significant run-off events during the sampling period. Consequently, only a limited discussion of tributary water quality will be presented in this report. Table 3 contains a summary of the water quality data for Punished Woman's Lake and its tributaries.

Table 3. Summary data for Punished Woman's Lake.

PUNISHED WOMAN LAKE WATER QUALITY DATA 1989
ALL CONCENTRATIONS IN MG/L

LOCATION		SITE	WTEMP	ATEMP	SDISK	DISOX	FLD_PH	FCOLI	CONDUCT	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P
OUTLET																			
	MEAN	1	45.83	47.17		10.82		20.91		8.07	133.33	326.83	281.92	20.50	0.15	0.20	1.08	0.099	0.021
	MIN	1	34.00	27.00		8.20		10.00		7.49	66.00	161.00	151.00	1.00	0.02	0.10	0.64	0.051	0.005
	MAX	1	63.00	73.00		14.00		80.00		8.41	182.00	436.00	395.00	53.00	0.47	0.40	2.14	0.227	0.098
TRIBUTARY																			
	MEAN	2	42.33	46.11		9.71		162.07		7.75	166.36	360.88	327.94	17.88	0.25	0.35	0.93	0.166	0.076
	MIN	2	30.00	27.00		5.00		0.00		7.20	34.00	107.00	93.00	2.00	0.02	0.10	0.10	0.034	0.005
	MAX	2	63.00	73.00		12.80		750.00		7.98	240.00	496.00	459.00	97.00	0.90	1.00	2.63	0.549	0.333
TRIBUTARY																			
	MEAN	3	37.83	41.33		11.03		100.00		7.47	59.07	318.50	285.00	30.33	0.54	0.68	1.87	0.311	0.184
	MIN	3	30.00	29.00		4.70		0.00		7.27	33.00	126.00	98.00	1.00	0.48	0.20	1.66	0.197	0.081
	MAX	3	64.00	69.00		13.40		360.00		7.68	102.00	942.00	897.00	86.00	0.74	1.10	2.31	0.556	0.390
IN-LAKE																			
	MEAN	4	52.06	50.19	1.81	10.21	6.23	9.61	431.50	8.65	161.00	414.64	352.03	57.90	0.07	0.11	1.11	0.089	0.009
	MIN	4	30.00	13.00	0.00	7.10	0.00	2.00	385.00	7.52	97.00	302.00	223.00	8.00	0.02	0.01	0.78	0.044	0.005
	MAX	4	75.00	82.00	5.75	17.00	8.80	10.00	510.00	9.60	429.00	629.00	573.00	120.00	0.38	0.50	1.48	0.183	0.029
IN-LAKE																			
	MEAN	5	53.18	51.18	1.65	9.59	4.79	23.68	440.44	7.62	156.27	412.27	350.20	62.07	0.14	0.13	1.19	0.113	0.015
	MIN	5	30.00	13.00	0.00	4.90	0.00	2.00	390.00	0.00	75.80	212.00	195.00	7.00	0.02	0.10	0.00	0.047	0.005
	MAX	5	76.00	82.00	5.50	12.50	8.50	220.00	510.00	9.24	286.00	653.00	589.00	206.00	0.86	0.80	2.21	0.312	0.207

Tributary Water Quality

The two tributaries were well oxygenated with mean dissolved oxygen concentrations of 9.7 and 11.0 mg/l at Sites 2 and 3. Values of pH were not unusual and averaged 7.8 and 7.5 units. Total solids, suspended solids, and dissolved solids were not abnormal and no exceedences of Water Quality criteria occurred. Fecal coliform counts at Sites 2 and 3 averaged 162 and 100/100 ml respectively and did not appear to present a major problem. Site 3, the southwest tributary consistently had mean nutrient concentrations nearly twice that of Site 2 (Table 3). Mean total nitrogen and total phosphorus concentrations at Sites 2 and 3 were 1.18 and 2.41 mg/l as N and .166 and .311 mg/l as P respectively.

Omernick (1977), in a nationwide survey, found that total nitrogen and total phosphorus concentrations on watersheds consisting of about 75% or more rangeland averaged 1.30 mg/l and .097 mg/l respectively. For total nitrogen, only Site 3 had a mean total nitrogen concentration greater than the nationwide average. Both sites had mean total phosphorus concentrations greater than the nationwide average of .097 mg/l. Site 3 consistently had nearly twice the mean nutrient and suspended solids concentrations of Site 2 (Table 3) and so nutrient and sediment controls should be prioritized towards the southwest tributary if water flows at Sites 2 and 3 are assumed to be similar.

In-lake Water Quality

Water temperature data indicated a well mixed lake with typical seasonal changes and with no thermal stratification. Temperature differences between the water surface and near the lake bottom were negligible (<2° C).

Dissolved oxygen concentrations in the lake ranged from 4.9 to 17 mg/l with means at Sites 4 and 5 of 10.2 and 9.6 mg/l respectively. This indicates a well oxygenated lake. Exceedences of the South Dakota Surface Water Quality (SDSWQ) criterion of 5.0 mg/l were noted only twice out of 86 dissolved oxygen measurements.

Values of pH in the lake ranged from 7.5 to 9.6 and 51% of the measurements were greater than the SDSWQ criterion range of 6.5 - 8.3 units. High pH readings are not uncommon in South Dakota lakes and it has been suggested that relatively high values (8.0 - 10.0) may be due to photosynthetic activity of algae and aquatic macrophytes (Sawyer and McCarty, 1978). Carbon dioxide is used during photoshythesis and this reduction in carbon dioxide will increase pH.

Total alkalinity ranged from 77 to 429 mg/l as $CaCO_3$ with mean values for Sites 4 and 5 of 161 and 156 mg/l respectively. These data indicate a well-buffered lake. There were no exceedences of the SDWQS criterion.

Total suspended solids ranged from 7 to 206 mg/l with means at Sites 4 and 5 of 58 and 62 mg/l, respectively. Only one sample exceeded the SDWQS criterion of 157.5 mg/l given the variation allowed for grab samples. Total dissolved solids ranged from 195 to 589 mg/l with means of 352 and 360 mg/l and no exceedences of the SDWQS criterion occurred.

Conductivity ranged from 385 to 510 umhos/cm and no samples exceeded the SDWQS criterion of 7,000 umhos/cm given the grab sample variation allowed.

Fecal coliform bacteria concentrations ranged from 2 to 220/100 ml with means of 10 and 24 cells/100 ml. No lake samples exceeded the SDWQS criterion of 400/100 ml and it appeared that fecal coliform bacteria were not a problem in the lake.

Nutrient concentrations indicated eutrophic conditions with mean total phosphorus concentrations of .089 and .113 mg/l at Sites 4 and 5. Mean orthophosphate concentrations by comparison were reasonably low (.009 and .015 mg/l) and this may be due to uptake by algae and macrophytes. Nitrogenous compounds varied in concentration. Mean Kjeldahl nitrogen and nitrite plus nitrate nitrogen concentrations were considered normal relative to other South Dakota lakes and were about 1.0 and .10 mg/l respectively. Ammonia concentrations averaged .07 and .14 mg/l at Sites 4 and 5 and 5 exceedences of SDWQS criterion for un-ionized ammonia occurred out of 99 in-lake samples collected.

Nitrogen:phosphorus ratios can be used to indicate the type of algae that may be most numerous in the lake. Nitrogen limitation favors the more noxious nitrogen-fixing blue-green algae. Nutrient co-limitation is a condition where neither nitrogen or phosphorus prevails. Forsberg (1980) proposed a co-limitation ratio range of 10-17 where ratios greater than 17 indicate phosphorus limitation and less than 10 indicate nitrogen limitation.

Total nitrogen: total phosphorus ratios indicated nutrient co-limitation with a mean ratio of 14.5. Although nutrient co-limitation may not favor a particular algal type, limited data on algae members suggested that blue-green algae (especially Aphanocapsa) predominate during the growing season (Appendix B). This may prove to be important if the macrophytes are significantly reduced in the lake. It is possible that significant macrophyte control in Punished Woman's Lake could result in a phytoplankton dominated lake (see discussion in Canfield et al., 1983) and the lake management strategy may subsequently change from macrophyte control to algae control.

Trophic state indices (TSI) are summary statistics that are often as a relative measures of lake quality. Carlson's 1977 TSIs were calculated from summer values of total phosphorus and Secchi disk. Mean TSI values for total phosphorus and Secchi disk were 51.1 and 66.4 respectively where values greater than 50 indicate eutrophic conditions. The two previous surveys of the lake had mean TSI values of 49 and 48, which denote mesotrophic conditions. The combined mean TSI for this study was 58.8 and is considerably greater than the two previous surveys. The lake appears to have degraded over the last eight to ten years, especially in water clarity. It is not known, however, whether this is due to algae or abiotic factors.

Lake Sediments

Table 4 contains the results of elutriate testing. Most parameters did not appear to increase appreciably in concentration after elutriate test mixing except for ammonia, Kjeldahl nitrogen, arsenic, barium, iron, manganese, and aluminum. Ammonia is readily used by algae for growth and any mixing of lake sediments, such as dredging or wind mixing, could provide enough nitrogen to produce bloom conditions. The increase in arsenic and the metals is not unusual and is comparable to elutriate testing results from other lakes in South Dakota (the SDWQS criteria for these elements was not exceeded).

The sediment survey (Figures 3 and 4) revealed an averaged depth of 1.59 meters (5.2 feet) compared to an average depth of 1.65 meters (5.4 feet) in 1971. Approximately .002 cubic kilometers (2,731,000 cubic yards) of soft sediment was estimated to be in the lake with the deepest sediments being located in the middle of the lake along most of its length and especially at the east end. The sources of this sediment are not known but is presumed to be bank erosion and from the watershed.

Land Use/Feedlot Analysis

The AGNPS Model was used to assess the condition of the watershed with respect to nutrient and sediment outputs and the effect of feedlots on those parameters. The model generated nutrient and sediment yields for each 16.2 hectare (40-acre) cell and for the watershed as a whole. Appendix C contains a detailed discussion of the procedure and results.

The analysis indicated that run-off from the watershed during a typical 5 year, 24-hour rainstorm with a total rainfall of 8.1 centimeters (3.2 inches) will contribute 2.87 million kilograms (3,162 tons) of sediment to the lake and average nutrient contributions in runoff of 1.32 Kg/Ha (0.69 lbs/ac) and 1.88 Kg/Ha (1.68 lbs/ac) for phosphate and nitrogen (without the inputs from feedlots).

The potential effect of 12 local feedlots on the total watershed output of nitrogen and phosphorus appeared noticeable (see Appendix C). Sediment output differences due to feedlots were not assessed because feedlots are generally not considered to be significant sediment sources.

One other purpose of this analysis is to permit a reasonable prioritization of areas that could potentially contribute sediment and nutrients to the lake. This prioritization can be used as a rough guide in implementing land use controls. The AGNPS model results indicated 34 cells (non-feedlot) as potentially significant in terms of nutrient and/or

Table 4. Punished Woman's elutriate test results.

DEPARTMENT OF THE ARMY
Missouri River Division, Corps of Engineers
Division Laboratory
Omaha, Nebraska

MRD Lab # 88/997

	Punished Woman's Lake, Sampled 4-19-88, Center of Lake, East End			Punished Woman's Lake, Sampled 4-19-88, Center of Lake, West End		
	SEDIMENT	RECEIVING WATER	ELUTRIATE WATER	SEDIMENT	RECEIVING WATER	ELUTRIATE WATER
AMMONIA, NH3, PPM	18.8 mg/kg	0.3 ppm	1.8 ppm	10.1 mg/kg	<0.1 ppm	1.4 ppm
CHEMICAL OXYGEN DEMAND, PPM	--	45.9 ppm	43.0 ppm	--	25.8 ppm	36.3 ppm
CYANIDE, TOTAL (as CN)	<2.0 mg/kg	<0.04 ppm	<0.04 ppm	<2.0 mg/kg	<0.04 ppm	<0.04 ppm
NITRATE, TOTAL (as N)	3.5 mg/kg	<0.1 ppm	<0.1 ppm	3.5 mg/kg	<0.1 ppm	<0.1 ppm
PHOSPHORUS, TOTAL (as P)	34 mg/kg	0.1 ppm	0.1 ppm	34 mg/kg	0.1 ppm	0.1 ppm
TOTAL KJELDAHL NITROGEN (as N)	53.9 mg/kg	1.0 ppm	2.6 ppm	78.1 mg/kg	0.9 ppm	2.0 ppm
OIL AND GREASE	29.7 mg/kg	1.7 ppm	2.7 ppm	84.5 mg/kg	3.7 ppm	2.1 ppm
ANTIMONY, TOTAL (as Sb)	<50 mg/kg	<2 ppb	<2 ppb	<50 mg/kg	<2 ppb	5.3 ppb
ARSENIC, TOTAL (as As)	10 mg/kg	3.1 ppb	27.2 ppb	13 mg/kg	2.4 ppb	15.0 ppb
BARIUM, TOTAL (as Ba)	45.9 mg/kg	80.1 ppb	145.3 ppb	46.2 mg/kg	78.5 ppb	149.4 ppb
BERYLLIUM, TOTAL (as Be)	<5 mg/kg	<2 ppb	<2 ppb	<5 mg/kg	<2 ppb	<2 ppb
CADMIUM, TOTAL (as Cd)	<5 mg/kg	<0.2 ppb	<0.2 ppb	<5 mg/kg	<0.2 ppb	1.8 ppb
CHROMIUM, TOTAL (as Cr)	<5 mg/kg	<1 ppb	<1 ppb	<5 mg/kg	<1 ppb	<1. ppb
COPPER, TOTAL (as Cu)	<5 mg/kg	<5 ppb	<5 ppb	<5 mg/kg	<5 ppb	<5 ppb
IRON, TOTAL (as Fe)	2900 mg/kg	17.7 ppb	29.9 ppb	3042 mg/kg	271.0 ppb	204.9 ppb
L[illegible], TOTAL (as Pb)	<5 mg/kg	0.6 ppb	0.5 ppb	<5 mg/kg	<0.2 ppb	1.4 ppb
[illegible]SIUM, TOTAL (as Mg)	1933 mg/kg	33.8 ppb	33.5 ppb	1947 mg/kg	34.4 ppb	34.9 ppb
MANGANESE, TOTAL (as Mn)	216 mg/kg	16.8 ppb	27.8 ppb	213 mg/kg	686.7 ppb	1190.4 ppb
MERCURY, TOTAL (as Hg)	<0.1 mg/kg	<1.0 ppb	<1.0 ppb	<0.1 mg/kg	<1.0 ppb	<1.0 ppb
SELENIUM, TOTAL (as Se)	<1 mg/kg	<2 ppb	<2 ppb	<1 mg/kg	<2 ppb	<2 ppb
ZINC, TOTAL (as Zn)	<50 mg/kg	59.1 ppb	53.9 ppb	<50 mg/kg	87.7 ppb	82.7 ppb
NICKEL, TOTAL (as Ni)	<5 mg/kg	<5 ppb	<5 ppb	<5 mg/kg	<5 ppb	<5 ppb
ALUMINUM, TOTAL (as Al)	3109 mg/kg	103.1 ppb	458.5 ppb	3207 mg/kg	163.1 ppb	499.4 ppb
CALCIUM, TOTAL (as Ca)	21167 mg/kg	47.9 ppb	56.8 ppb	21367 mg/kg	47.4 ppb	55.9 ppb
SODIUM, TOTAL (as Na)	46.7 mg/kg	33.5 ppb	34.9 ppb	46.7 mg/kg	33.8 ppb	34.4 ppb
POTASSIUM, TOTAL (as K)	500 mg/kg	4.3 ppb	5.4 ppb	513 mg/kg	4.5 ppb	5.7 ppb
SILVER, TOTAL (as Ag)	<5 mg/kg	<0.2 ppb	<0.2 ppb	<5 mg/kg	<0.2 ppb	<0.2 ppb
CHLORINATED PESTICIDES	<0.5 mg/kg	<0.5 ppb	<0.5 ppb	<0.5 mg/kg	<0.5 ppb	<0.5 ppb
PCB	<50 ug/kg	<50 ppb	<50 ppb	<50 ug/kg	<50 ppb	<50 ppb

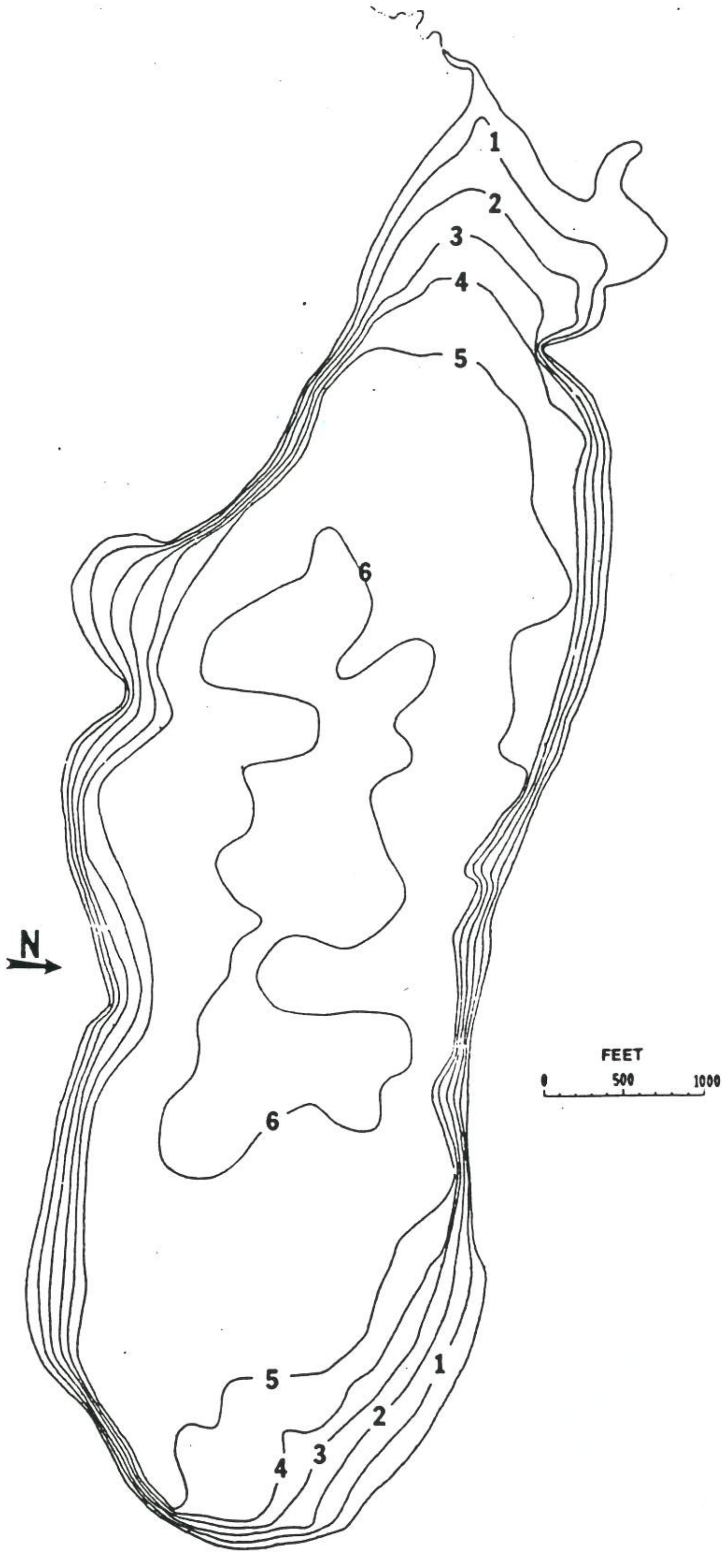

Figure 3. Bottom contour map for Punished Woman's Lake. Contours in feet.

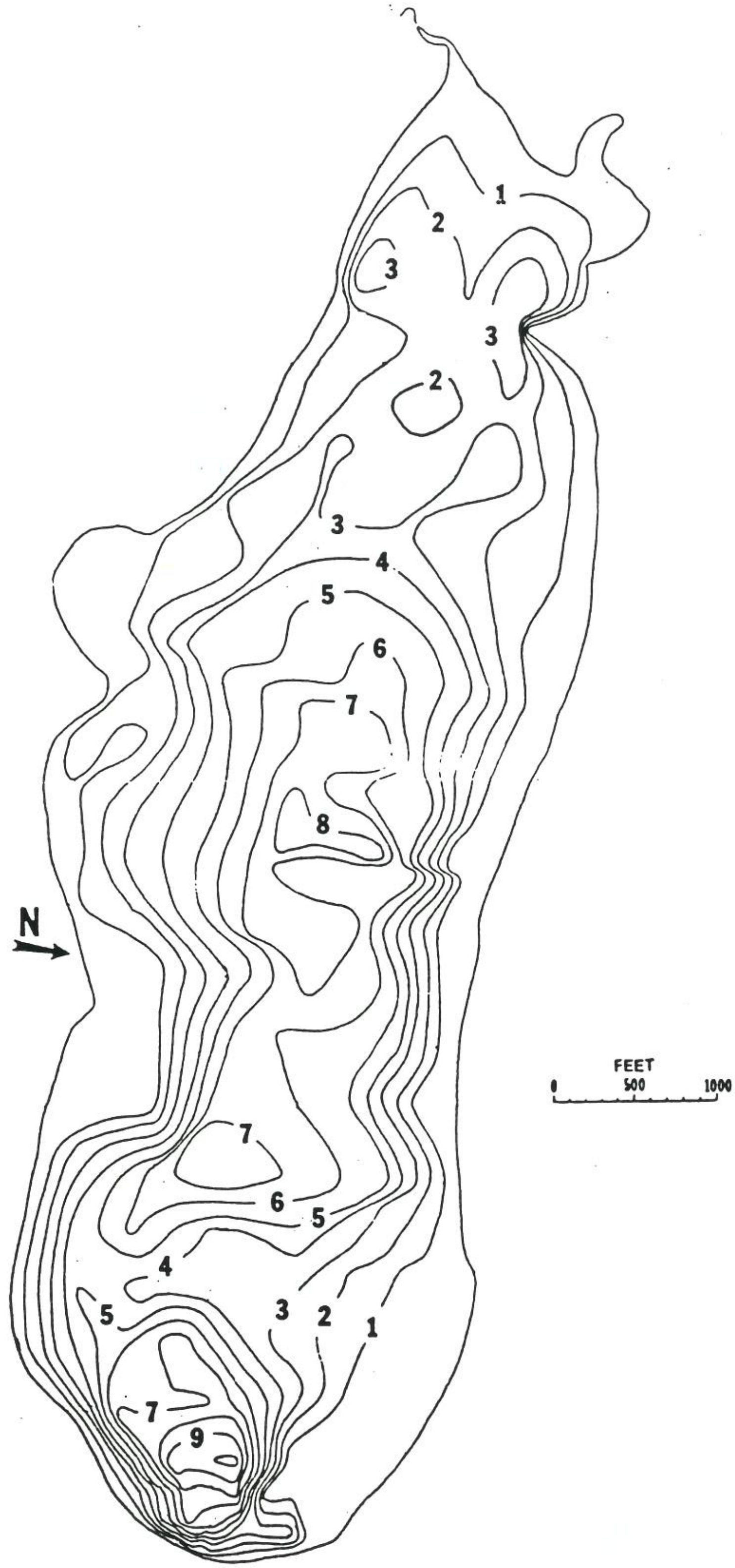

Figure 4. Sediment depth contour map for Punished Woman's Lake. Contours in feet.

sediment yield and an additional four feedlots were identified as potentially significant. These cells should be field checked by qualified personnel (eg. Conservation District employees or SCS personnel) before these areas are targeted for erosion/nutrient control strategies. Legal descriptions for these cells are given in Appendix C.

Conservation practices such as conservation tillage, contour farming, contour stripcropping, crop rotation, terraces, grassed waterways, animal waste management systems, and range and pasture management may be the most appropriate BMPs in this watershed. Additional consultation with the Conservation District is recommended before specific BMPs are chosen.

RESTORATION TECHNIQUES FOR MACROPHYTE CONTROL

Aquatic macrophytes, the major problem in Punished Woman's Lake, usually proliferate in response to adequate light levels and nutrient rich sediments (USEPA, 1988). Both conditions are present in Punished Woman's Lake. Shallow lakes are especially prone to having extensive macrophyte coverage because of high light availability and high siltation can create the shallowness favorable for macrophyte growth.

There are a number of methods available to control aquatic macrophytes and most are oriented towards macrophyte elimination rather than prevention. The following narrative contains discussions on various macrophyte control techniques. More detailed information can be found in the Lake and Reservoir Restoration Guidance Manual (USEPA, 1988).

Water Level Drawdown

Rooted aquatic macrophytes can sometimes be controlled by lowering water levels to the extent that the macrophytes and their roots are exposed to freezing and drying. The technique, however, is species specific and resistant species may increase or encroach into areas where susceptible species were controlled. Drawdown times vary from seasonal (e.g. overwinter) to year-long drawdowns but it is clear that lake use will be limited during any major drawdown.

A small scale drawdown has already occurred to Punished Woman's Lake. In 1971, the outlet structure was raised eight inches to allow for additional water storage and to benefit the lakes fisheries. The elevated water levels and associated wave action resulted in shoreline erosion and bank sloughing. In 1988, permission was granted by the South Dakota Board of Water Management to remove the eight inch cap from the outlet structure and the cap was subsequently removed. Although the major effect of the cap removal will be to arrest further shoreline erosion, macrophytes established along the shoreline are now being exposed to weathering. This may provide a modest degree of macrophyte control along the shoreline. Mid-lake macrophytes, however, will not be effected.

Shading and Sediment Covers

Because light is critical for macrophyte growth, various techniques have been devised to limit the amount of light reaching macrophytes. Surface shading and dyes have not been extensively used because they decrease lake aesthetics and sediment covers have received more attention.

Various materials have been tried as sediment covers and range from burlap to synthetics. Their success depends upon effective placement, stability, and permeability to gases. Costs vary with the materials used and generally range from approximately

$1,000 - 3,000/acre although costs have reached as high as $8,000/acre.

This technique could be used in Punished Woman's Lake, especially in near-shore areas for long-term control of macrophytes.

Biological Controls

Biological controls have long been used in agriculture to control weeds and crop insect pests and a similar approach has recently found its way into lake restoration. The idea is to introduce an organism that will either eat or cause disease in aquatic plants to the extent that plant control is realized.

Grass carp (Ctemopharyngoon, idealla) is the most widely known biological control of aquatic macrophytes and this fish readily consumes plant species such as elodea, pondweed, and hydrilla. In South Dakota, the importation and use of grass carp is strictly controlled and has only been allowed under permit by the South Dakota Department of Game, Fish and Parks. Experiments on the use of grass carp for macrophyte control have been conducted in South Dakota but statewide use of this fish will not likely occur until a complete understanding of the fish and its effect on lake ecosystems is obtained. Under the circumstances, this technique is not advised at this time.

Harvesting

Harvesting aquatic macrophytes is accomplished by cutting and removing nuisance plants. A variety of harvesting equipment exist and range from relatively simple hand-held cutters to large mechanical harvesters that cut and remove the cuttings. This removal is important because unharvested cuttings can release nutrients and organic matter and potentially produce anoxic conditions through bacterial decomposition.

Harvesters produce immediate results but the process is relatively slow with cutting rates ranging from about .08 to .24 hectares (0.2 to 0.6 acres) per hour. Given these rates, it would take approximately 99 to 298 eight-hour work days to cover the total area of the lake. Considering the length of time to cover the whole lake, it is questionable whether the macrophytes can be harvested fast enough to have any lasting impact. Harvesting, however, may be useful to control plants in small areas and consideration should be given to this option. Harvesting costs may range from $135 to $300 per acre and other factors, such as disposal of the cuttings, should be considered.

Herbicides

Herbicides have long been used to control nuisance algae and macrophytes. Herbicide effectiveness, although relatively rapid, is considered short-term and repeated treatments are often required. With this in mind, it is not considered a viable long-term solution for Punished Woman's Lake but it should be considered for the control of weeds in small areas.

Herbicides vary considerably in their formulation, required dosages, restrictions, etc. and extreme care should be taken in selecting an appropriate herbicide. Herbicide use in South Dakota waters also requires an approved variance from South Dakota Surface Water Quality Standards by the Board of Water Management and an application permit from the South Dakota Department of Game, Fish and Parks.

Sediment Removal

Sediment removal can control aquatic macrophytes by physically removing the plants, deepening enough to produce light-limiting conditions, and by removing nutrient rich sediments that are favorable for macrophyte growth.

Sediment removal is usually accomplished by dredging or through the use of land based equipment after the lake sediments have been exposed and dried.

The use of land based equipment is only viable if one is willing to dewater the lake for a considerable period of time. Given the extensive connection with the underlying aquifer, it is questionable whether the lake sediments can dry thoroughly enough to permit the use of land based equipment.

Dredging is often used to increase lake capacity and to remove nutrient rich sediments that promote algal growth. Dredging can also be an effective long-term control of macrophytes if enough sediments are removed to deepen the lake such that light (or the lack thereof) limits macrophyte growth.

Canfield et al. (1985) derived equations for lakes in Florida and Wisconsin to estimate the maximum depth of colonization (MDC) by macrophytes. The MCD is a function of water transparency as determined by a Secchi disk and in Wisconsin lakes the equation is:

$$\log MCD - 0.79 \log SD + 0.25$$

where SD = Secchi depth in meters.

Given the maximum SD reading during the summer (1.68 meters), Punished Woman's Lake should be deepened to at least a depth of 2.67 meters (about 9 feet) for effective macrophyte control through light limitation. The equation only provides an estimate of the MDC and prudence would dictate dredging at least an extra foot or two.

The mechanics and logistics of dredging is well known by SDDENR and a detailed discussion will not be presented here. Dredging is an expensive technique and the dredging costs in South Dakota are about $1.50 - $2.00 per cubic yard of sediment.

These costs may limit the extent of dredging, especially whole lake dredging, and consideration should be given towards combining this technique with techniques more useful for near-shore areas.

Land Use Controls

The shallowness of Punished Woman's Lake is favorable for macrophyte growth and is a direct result of siltation either through shoreline erosion or tributary inputs. The removal of the eight-inch cap on the outlet structure is a first step in controlling shoreline erosion but shoreline stabilization in some areas may be required. The Punished Woman's Lake Association has already taken steps to riprap selected areas and a 404 permit has been granted by the U.S. Army Corps of Engineers.

Controlling tributary inputs, however, is a far more difficult task and requires a major effort to prevent erosion in the watershed. The AGNPS model was used to prioritize areas with respect to sediment yield and nutrient output and efforts should begin in these areas. A number of financial and technical assistance programs exist that can be used for nutrient and erosion control and additional information on these programs can be obtained from SDDENR. Costs for erosion control vary greatly and depend upon the control measure and other program attributes.

LITERATURE CITED

American Public Health Association. 1985. Standard methods for the examination of water and wastewater. APHA, Washington, D.C. 1268p.

Canfield, D.E., Jr., K.A. Langeland, S.D. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. Journal of Aquatic Plant Management 23:25-28.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22(2):361-369.

Forsberg, C. 1980. Present knowledge on limiting nutrients, p.37. In Restoration of Lakes and Inland Waters. U.S. Environmental Protection Agency. EPA 440/5-81-010. Washington, D.C.

Koth, R.M. 1981. South Dakota lakes survey. South Dakota Department of Water and Natural Resources, Office of Water Quality. Joe Foss Building, Pierre, South Dakota. 688p.

Lind, C.T. 1974. Handbook of common methods in limnology. V.C. Mosby Co., St. Louis, Missouri. 154p.

Omernick, J.M. 1977. Nonpoint source-stream nutrient level relationships: a nationwide study. U.S. Environmental Protection Agency. EPA-600/3-77-105. Corvallis, Oregon. 106p.

Sawyer, C.N. and P.L. McCarty. 1978. Chemistry for Environmental Engineering, 3rd. ed. McGraw-Hill Co., New York.

State Lakes Preservation Committee. 1977. A plan for the classification, preservation, and restoration of lakes in northeastern South Dakota. Report prepared for the Governor and Legislature of South Dakota and the Old West Regional Commission. Joe Foss Building, Pierre, South Dakota. 268p.

U.S. Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1988. The Lake and Reservoir Restoration Guidance Manual. EPA 440/5-88-002. Washington, D.C.

Young, R.A., C.A. Onstad, D.D. Bosh, and W.P. Anderson. 1986. AGNPS, agricultural nonpoint source pollution model. USDA-APS Conservation Reserch Report 35.

APPENDIX A

Parameter Justifications

WATER QUALITY PARAMETERS

1. Laboratory analysis

   a. Fecal coliform (organisms/100 mg) can indicate fecal contamination and thus potential human health hazards. Fecal coliform bacteria are bacteria which live in the digestive tract of warm-blooded animals. These bacteria are considered to be an indicator of sewage pollution or livestock manure. Fecal coliform bacteria are not found in the ingestive tract of cold-blooded animals such as fish, amphibians or reptiles. Some fecal coliform will exist in nature from the fecal material of wild animals or birds.

   b. Biochemical oxygen demand (BOC) (mg/l) is used to measure the organic content in polluted waters. BOD is a measurement of the potential for oxygen removal from the water and an indicator of organic pollution. As organisms die, the process of decomposition by bacteria removes dissolved oxygen from the water. The more nutrient rich the environment, the more potential for growth of aquatic organisms; hence, there will be more bacterial decomposition.

   c. Lab pH (su) is a measurement of the hydrogen ion activity which directly affects the toxicity (solubility) of heavy metals in water, among other items. The pH scale is a number range between 1 and 14 with 7 being neutral. Any value less than 7 is considered acidic, and value greater than 7 is considered basic.

   d. Suspended solids (mg/l) can indicate the sediment load into a body of water and possible problems to the biological community. Suspended solids does not include a measure of larger particles that are moved along the stream bed during high flows.

   e. Total solids (mg/l) are used to determine dissolved solids by subtracting suspended solids from total solids. Dissolved solids may have a detrimental affect on the biological community.

   f. Ammonia-nitrogen (mg/l) is a product of the first oxidative step in degrading organic material. It is directly available to plants as a nutrient for growth. Ammonia can be used as evidence of organic pollution and the unionized fraction of ammonia is toxic to fish.

   g. Nitrite-nitrogen (mg/l) constitutes the inorganic nitrogen fraction which is used by phytoplankton. Nitrate-nitrogen (mg/l) also indicates pollution from animal wastes, fertilizers or nitrogenous organic matter which are used by algae. It gives an indication as to what may be causing pollution in a lake (i.e., fertilizers, animal wastes, nitrogenous organic matter).

h. Total Kjeldahl Nitrogen (mg/l) is used to measure both ammonia and organic nitrogen. Ammonia is subtracted from TKN and results in the organic nitrogen fraction which can be broken down to nitrogen compounds which are utilized by phytoplankton.

i. Total phosphorus (mg/l) represents all of the phosphorus found in the water sample. Not all of the phosphorus is immediately available to aquatic plants and algae. Phosphorus is an element which is essential to all life and is the least available to living organisms. For this reason, phosphorus is commonly the limiting factor for biological productivity. When phosphorus concentrations are high, nuisance growth of aquatic plants or algae may result.

j. Ortho-phosphorus (mg/l) is analyzed because it is phosphorus which is immediately available to algae.

Field Analysis

a. Water temperature (F or C) is taken since it has considerable effect on the chemical processes in a lake. Also, temperature is important to fish life and other aquatic species.

b. Field pH (su) measures the hydrogen ion activity which can affect the toxicity of heavy metals in the water, as well as other factors.

c. Dissolved oxygen (mg/l) is an indicator of the overall health of the lake and it is needed to sustain most aquatic animal life.

d. Climatic conditions - wind, precipitation, air temperature (F or C).

e. Visual observations - septic conditions, odor, water color, turbidity or anything unusual (e.g. dead fish).

f. Tributary flow depth (ft.) to calculate flows entering the lake.

g. The following additional measurements are taken for in-lake analysis: water depth, oxygen profiles, composite sampling at various lake depths (surface, mid-depth and bottom), chlorophyll a, Secchi Disc (visibility) and phytoplankton identification.

In-lake sediment sampling

a. Corps of Engineers Elutriate Test for some of the above mentioned parameters plus selected pesticides; such as Endrin, DT, parathion, Etc., is used to determine what is in the sediments.

b. Sediment depth measurements are used to determine sediment volumes in the lake.

APPENDIX B

Original Chemical and Biological Data

Table 5. Original water quality data for Punished Woman's Lake.

PUNISHED WOMAN LAKE WATER QUALITY DATA 1989
ALL CONCENTRATIONS IN MG/L

PROJECT	SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	SDISK	DISOX	FLD_PH	FCOLI	CONDUCT.	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P
PUNISHED WOMAN LAKE	1	29-Mar-89	1400	GRAB	SURFACE	34	49		11		10		7.64	66.2	161	151	1	0.47	0.4	2.14	0.227	0.098
PUNISHED WOMAN LAKE	1	03-Apr-89	1000	GRAB	SURFACE	34	35		10.8		10		7.49	83.8	189	177	12	0.41	0.4	1.26	0.146	0.056
PUNISHED WOMAN LAKE	1	06-Apr-89		GRAB	SURFACE	36	30		12.7		10		7.95	80.8	203	174	2	0.18	0.4	0.99	0.071	0.015
PUNISHED WOMAN LAKE	1	12-Apr-89	1000	GRAB	SURFACE	35	27		14		10		8.03	134	337	307	2	0.0[illegible]	0.2	0.81	0.064	0.021
PUNISHED WOMAN LAKE	1	20-Apr-89	745	GRAB	SURFACE	42	44		12.8		10		8.41	138	336	309	10	0.0[illegible]	0.1	1.27	0.071	0.008
PUNISHED WOMAN LAKE	1	25-Apr-89	900	GRAB	SURFACE	52	47		9.5		60		8.27	140	346	288	28	0.02	0.1	1.26	0.088	0.005
PUNISHED WOMAN LAKE	1	28-Apr-89	930	GRAB	SURFACE	50	38		9.7				8.15	141	309	279	34	0.02	0.1	1.04	0.078	0.005
PUNISHED WOMAN LAKE	1	03-May-89	1045	GRAB	SURFACE	47	60		11.3		10		8.39	150	380	324	28	0.02	0.1	1.28	0.098	0.014
PUNISHED WOMAN LAKE	1	09-May-89	845	GRAB	SURFACE	45	48		10.9		10		8.28	166	414	338	44	0.02	0.1	0.71	0.071	0.008
PUNISHED WOMAN LAKE	1	16-May-89	845	GRAB	SURFACE	60	73		8.9		10		8.31	154	365	302	53	0.02	0.1	0.64	0.051	0.008
PUNISHED WOMAN LAKE	1	24-May-89	945	GRAB	SURFACE	63	67		8.2		10		8.27	163	424	399	2	0.04	0.1	0.77	0.105	0.005
PUNISHED WOMAN LAKE	1	31-May-89	1045	GRAB	SURFACE	52	48		10		80		7.67	182	438	395	30	0.29	0.3	0.83	0.122	0.008
PUNISHED WOMAN LAKE	2	11-Mar-89	830	GRAB	SURFACE	30	29		12.8				7.2	39	178	163	34	0.762	1	2.57	0.549	0.333
PUNISHED WOMAN LAKE	2	13-Mar-89	1000	GRAB	SURFACE	30	31		12.1		1.1		7.25	34.2	142	120	18	0.9	1	2.6	0.403	0.257
PUNISHED WOMAN LAKE	2	24-Mar-89	1100	GRAB	SURFACE	31	33		12				7.25	34.8	107	93	8	0.9	0.9	2.63	0.315	0.132
PUNISHED WOMAN LAKE	2	27-Mar-89	915	GRAB	SURFACE	31	35		12.1		270							0.54	0.3	1.5	0.294	
PUNISHED WOMAN LAKE	2	29-Mar-89	1330	GRAB	SURFACE	39	49		11		70		7.71	51.6	141	123	12	0.37	0.3	1.47	0.278	0.136
PUNISHED WOMAN LAKE	2	03-Apr-89	930	GRAB	SURFACE	33	35		10.4		10		7.64	137	301	288	12	0.34	0.3	1.22	0.136	0.052
PUNISHED WOMAN LAKE	2	06-Apr-89		GRAB	SURFACE	38	30		10.2		30		7.86	167	358	328	2	0.2	0.3	0.49	0.071	0.039
PUNISHED WOMAN LAKE	2	12-Apr-89	900	GRAB	SURFACE	33	27		11.2		10		7.84	213	421	397	2	0.07	0.4	0.17	0.051	0.027
PUNISHED WOMAN LAKE	2	20-Apr-89	845	GRAB	SURFACE	42	44		9.6		10		7.92	219	408	404	2	0.03	0.1	0.42	0.041	0.012
PUNISHED WOMAN LAKE	2	25-Apr-89	830	GRAB	SURFACE	47	45		8.5		30		7.88	210	472	415	12	0.05	0.3	0.6	0.078	0.022
PUNISHED WOMAN LAKE	2	28-Apr-89	900	GRAB	SURFACE	41	38		9.5				7.86	209	496	459	22	0.03	0.1	0.36	0.064	0.014
PUNISHED WOMAN LAKE	2	03-May-89	1000	GRAB	SURFACE	44	60		11.4		10		7.98	218	461	441	18	0.03	0.1	0.1	0.044	0.017
PUNISHED WOMAN LAKE	2	09-May-89	800	GRAB	SURFACE	41	48		9.9		60		7.9	229	470	439	6	0.02	0.1	0.24	0.034	0.014
PUNISHED WOMAN LAKE	2	16-May-89	815	GRAB	SURFACE	53	73		9.1		140		7.96	234	422	372	2	0.02	0.1	0.19	0.051	0.005
PUNISHED WOMAN LAKE	2	24-May-89	1000	GRAB	SURFACE	56	67		7.7		550		7.84	238	462	399	2	0.02	0.1	0.37	0.061	0.005
PUNISHED WOMAN LAKE	2	31-May-89	1030	GRAB	SURFACE	47	48		5		490		7.94	240	456	424	22	0.0[illegible]	0.1	0.1	0.064	0.015
PUNISHED WOMAN LAKE	2	20-Jul-89	0	GRAB	S	63	69		6.6		750		7.95	238	425	328	37	0.08	0.10	0.55	0.119	0.020
PUNISHED WOMAN LAKE	2	29-Jul-89	845	GRAB	S	63	69		5.6			0	7.95	125	415	382	33	0.16	0.70	1.22	0.403	0.196
PUNISHED WOMAN LAKE	3	11-Mar-89	930	GRAB	SURFACE	30	29		13.4				7.27	33	145	103	22	0.41	1	1.71	0.251	0.12
PUNISHED WOMAN LAKE	3	13-Mar-89	830	GRAB	SURFACE	31	33		12.7		360		7.27	39.8	147	130	16	0.52	1.1	1.88	0.271	0.141
PUNISHED WOMAN LAKE	3	24-Mar-89	1005	GRAB	SURFACE	31	33		13.1				7.27	39.8	126	98	12	0.5	0.7	1.66	0.197	0.081
PUNISHED WOMAN LAKE	3	27-Mar-89	845	GRAB	SURFACE	32	35		11.9		30		7.68	60.8	186	134	86	0.74	0.3	1.85	0.322	0.221
PUNISHED WOMAN LAKE	3	29-Mar-89	1300	GRAB	SURFACE	39	49		10.4		10		7.67	102	365	348	1	0.58	0.2	1.81	0.268	0.15
PUNISHED WOMAN LAKE	3	29-Jul-89	820	GRAB	S	64	69		4.7		0		7.64	79	942	897	45	0.43	0.80	2.31	0.556	0.390
PUNISHED WOMAN LAKE	4	10-Aug-88	1115	GRAB	BOTTOM	70	76	1.6	8.1	8.8	10			156	446	375	71	0.02	0.1	0.84	0.115	0.006
PUNISHED WOMAN LAKE	4	10-Aug-88	1115	GRAB	SURFACE	70	76	1.6	8.6	8.8	10			157	453	378	75	0.02	0.1	0.87	0.139	0.005
PUNISHED WOMAN LAKE	4	23-Aug-88	830	GRAB	SURFACE	65	60	1.5	7.9	5.1	10			156	407	365	42	0.02	0.1	1.27	0.142	0.015
PUNISHED WOMAN LAKE	4	23-Aug-88	830	GRAB	BOTTOM	62	60		8.8	5.1	10			155	406	363	43	0.02	0.1	1.35	0.159	0.006
PUNISHED WOMAN LAKE	4	26-Sep-88	905	GRAB	BOTTOM	53	61		9.5		10		8.64	161	438	361	77	0.02	0.1	1.16	0.115	0.005
PUNISHED WOMAN LAKE	4	26-Sep-88	905	GRAB	SURFACE	52	61	1.5	9.8		10		8.61	162	432	370	62	0.02	0.1	1.22	0.115	0.005
PUNISHED WOMAN LAKE	4	11-Oct-88	930	GRAB	SURFACE	43	35	2.5	10.7		10		8.68	168	397	361	36	0.02	0.1	1.1	0.095	0.005
PUNISHED WOMAN LAKE	4	11-Oct-88	930	GRAB	BOTTOM	43	35		10.6		10		8.67	168	398	354	44	0.0[illegible]	0.01	1.04	0.078	0.005
PUNISHED WOMAN LAKE	4	02-Nov-88	1000	GRAB	SURFACE	34	39	1.2	12.4		10		8.26	186	450	364	86	0.17	0.1	1.12	0.122	0.018
PUNISHED WOMAN LAKE	4	02-Nov-88	1000	GRAB	BOTTOM	34	39		12.6		10		8.28	187	451	369	82	0.17	0.1	1.24	0.122	0.011
PUNISHED WOMAN LAKE	4	19-Dec-88	930	GRAB	BOTTOM	36	26		17	6.4	10			221	510			0.03	0.1	0.96	0.058	0.005
PUNISHED WOMAN LAKE	4	19-Dec-88	930	GRAB	SURFACE	33	26	2.8	16.5	6.8	10			218	508			0.04	0.1	1.03	0.054	0.005
PUNISHED WOMAN LAKE	4	18-Jan-89	930	GRAB	SURFACE	33	25	4	10.8	7.2	10			246	629	560	69	0.15	0.1	1.39	0.051	0.005
PUNISHED WOMAN LAKE	4	18-Jan-89	930	GRAB	BOTTOM	35	25		10.2	6.8	10			242	617	573	44	0.17	0.1	1.26	0.051	0.005
PUNISHED WOMAN LAKE	4	07-Feb-89	94[illegible]	GRAB	BOTTOM	33	13		11.4	7	10			267	623	563	60	0.11	0.1	1.33	0.044	0.005
PUNISHED WOMAN LAKE	4	07-Feb-89	94	GRAB	SURFACE	31.5	13	5.75	11.1	6.5	10			429	622	572	50	0.11	0.1	1.26	0.044	0.005
PUNISHED WOMAN LAKE	4	09-Mar-89	1000	GRAB	SURFACE	30	33	1.5	9.6		10		7.52	139	353	320	33	0.38	0.5	1.34	0.115	0.019
PUNISHED WOMAN LAKE	4	09-Mar-89	1000	GRAB	BOTTOM	33	33		7.1		10		7.56	239	569	520	49	0.25	0.3	1.16	0.075	0.006
PUNISHED WOMAN LAKE	4	24-Apr-89	815	GRAB	BOTTOM	53	52		9		10		7.94	151	368	319	49	0.02	0.1	1.21	0.081	0.005
PUNISHED WOMAN LAKE	4	24-Apr-89	815	GRAB	SURFACE	52	52	1.3	8.7		10		7.91	149	361	313	48	0.02	0.1	1.23	0.092	0.009
PUNISHED WOMAN LAKE	4	09-May-89	1000	GRAB	SURFACE	47	54	2.4	10.9		10		8.45	143	380	313	67	0.02	0.1	0.81	0.075	0.007
PUNISHED WOMAN LAKE	4	09-May-89	1000	GRAB	BOTTOM	47	54		11		10		8.45	143	381	320	61	0.02	0.1	0.78	0.061	0.008
PUNISHED WOMAN LAKE	4	24-May-89	830	GRAB	SURFACE	65	64	1.6	8.4		10		8.37	163	424	325	99	0.0[illegible]	0.1	0.92	0.108	0.005

Table 5. Continued.

PUNISHED WOMAN LAKE WATER QUALITY DATA 1989
ALL CONCENTRATIONS IN MG/L

PROJECT	SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	SDISK	DISOX	FLD_PH	FCOLI	CONDUCT.	LAB PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P
PUNISHED WOMAN LAKE	4	24-May-89	830	GRAB	BOTTOM	63	64		8.7		10		8.3	162	431	329	102	0.02	0.1	0.99	0.119	0.005
PUNISHED WOMAN LAKE	4	02-Jun-89		GRAB	S	65	96	2.2	10.0		10	484	8.63	149	361	352	9	0.02	0.10	0.90	0.068	0.007
PUNISHED WOMAN LAKE	4	14-Jun-89	1100	GRAB	B	54	49		9.6		10	499	8.38	162	428	356	72	0.02	0.10	1.11	0.088	0.005
PUNISHED WOMAN LAKE	4	14-Jun-89		GRAB	S	54	49	2.1	10.0		10	510	8.40	164	431	355	76	0.02	0.10	0.85	0.088	0.008
PUNISHED WOMAN LAKE	4	27-Jun-89	820	GRAB	B	64	56		9.8		10	474	8.61	148	368	360	8	0.02	0.10	0.87	0.068	0.005
PUNISHED WOMAN LAKE	4	06-Jul-89	1430	GRAB	B	75	82		9.0		10	420	9.15	116	330	299	31	0.04	0.10	1.05	0.051	0.014
PUNISHED WOMAN LAKE	4	06-Jul-89	1230	GRAB	S	75	82	2.2	9.4		10	416	9.17	113	334	301	33	0.05	0.10	1.04	0.064	0.018
PUNISHED WOMAN LAKE	4	20-Jul-89	930	GRAB	S	+ 69	69	5.5	10.5		10	402	9.57	103	332	223	109	0.08	0.10	0.82	0.051	0.005
PUNISHED WOMAN LAKE	4	20-Jul-89	930	GRAB	B	+ 68	69		10.5			402	9.60	102	327	228	99	0.08	0.10	0.99	0.061	0.005
PUNISHED WOMAN LAKE	4	08-Aug-89	830	GRAB	B	63	58		9.3		10	385	9.47	99	353	283	70	0.05	0.10	1.39	0.088	0.019
PUNISHED WOMAN LAKE	4	08-Aug-89	830	GRAB	S	+ 64	58	1.5	9.0		10	385	9.43	99	355	295	60	0.24	0.10	1.33	0.081	0.029
PUNISHED WOMAN LAKE	4	31-Aug-89	1030	GRAB	B	65	63		9.0		2	397	9.38	97	302	278	24	0.06	0.10	1.09	0.058	0.007
PUNISHED WOMAN LAKE	4	31-Aug-89	1030	GRAB	S	66	63	2.3	9.0		2	390	9.39	99	306	268	38	0.05	0.10	1.08	0.068	0.010
PUNISHED WOMAN LAKE	4	11-Sep-89	930	GRAB	S	53	43	2.5	9.3		10	403	9.15	103	310	287	23	0.04	0.10	0.98	0.068	0.006
PUNISHED WOMAN LAKE	4	11-Sep-89	930	GRAB	B	51	43		10.0		10	397	9.11	102	310	290	20	0.04	0.10	1.31	0.071	0.005
PUNISHED WOMAN LAKE	4	28-Sep-89	1015	GRAB	S	54	55	1.5	10.3		10	432	8.51	127	384	264	120	0.03	0.20	1.48	0.176	0.027
PUNISHED WOMAN LAKE	4	28-Sep-89	1015	GRAB	B	54	55		10.3		10	429	8.45	130	377	293	84	0.03	0.10	1.32	0.183	0.011
PUNISHED WOMAN LAKE	4	18-Oct-89	1200	GRAB	B	38	41		11.8		10	471	8.45	136	376	329	47	0.05	0.10	1.04	0.098	0.005
PUNISHED WOMAN LAKE	4	18-Oct-89	1200	GRAB	S	38	41	1.5	12.0		10	471	8.45	135	377	333	44	0.04	0.10	0.90	0.108	0.007
PUNISHED WOMAN LAKE	5	10-Aug-88	1030	GRAB	BOTTOM	72	76	1.8	8.2	8.5	10			163	466	387	79	0.02	0.1	0.94	0.247	0.005
PUNISHED WOMAN LAKE	5	10-Aug-88	1030	GRAB	SURFACE	70	76	1.8	8.5	8	10			163	450	391	59	0.02	0.1	0.91	0.115	0.005
PUNISHED WOMAN LAKE	5	23-Aug-88	940	GRAB	SURFACE	66	61	1.5	7.6	5.1	10			157	413	356	57	0.02	0.1	1.41	0.149	0.005
PUNISHED WOMAN LAKE	5	23-Aug-88	940	GRAB	BOTTOM	65	61		7.5	5.5	10			158	420	360	60	0.02	0.1	1.13	0.146	0.005
PUNISHED WOMAN LAKE	5	13-Sep-88		GRAB	BOTTOM	54	51		9.5	5.9	10			178	570	364	206	0.03	0.1	1.19	0.102	0.005
PUNISHED WOMAN LAKE	5	13-Sep-88		GRAB	SURFACE	54	51	1.9	10.4	5.5	10			154	416	368	48	0.02	0.1	1.23	0.105	0.005
PUNISHED WOMAN LAKE	5	13-Sep-88		GRAB	BOTTOM	58	56		9.2	5.5	10			165	469	357	112	0.02	0.1	1.18	0.142	0.005
PUNISHED WOMAN LAKE	5	13-Sep-88		GRAB	SURFACE	55	56	1.7	9.3	5.3	90			157	429	378	51	0.03	0.1	1.24	0.122	0.005
PUNISHED WOMAN LAKE	5	26-Sep-88	830	GRAB	BOTTOM	52.8	58		9.5		10		8.61	162	434	365	69	0.02	0.1	1.14	0.108	0.005
PUNISHED WOMAN LAKE	5	26-Sep-88	830	GRAB	SURFACE	52	58	1.75	9.9		10		8.63	198	431	361	70	0.02	0.1		0.112	0.005
PUNISHED WOMAN LAKE	5	11-Oct-88	830	GRAB	BOTTOM	43	34		10.3		10		8.64	188	398	349	49	0.02	0.1	0.99	0.088	0.005
PUNISHED WOMAN LAKE	5	11-Oct-88	830	GRAB	SURFACE	43	34	2	10.5		10		8.63	188	396	357	39	0.02	0.1	1.08	0.081	0.005
PUNISHED WOMAN LAKE	5	02-Nov-88	900	GRAB	BOTTOM	35	39		12.5		10		8.26	186	469	377	92	0.17	0.1	1.16	0.139	0.013
PUNISHED WOMAN LAKE	5	02-Nov-88	900	GRAB	SURFACE	33	39	1	12.5		10		8.26	188	461	373	88	0.17	0.1	1.24	0.132	0.01
PUNISHED WOMAN LAKE	5	18-Jan-89	830	GRAB	BOTTOM	31.5	25		9.3	6.8	10			253	637	572	65	0.42	0.1	1.84	0.061	0.007
PUNISHED WOMAN LAKE	5	18-Jan-89	830	GRAB	SURFACE	31.5	25	4.5	9.3	6.4	10			252	636	575	61	0.41	0.1	1.51	0.064	0.005
PUNISHED WOMAN LAKE	5	07-Feb-89	845	GRAB	BOTTOM	34	13		4.9	6.3	10			282	642	587	55	0.85	0.1	2.21	0.068	0.017
PUNISHED WOMAN LAKE	5	07-Feb-89	845	GRAB	SURFACE	31	13	5	5.7	6.9	10			286	653	589	64	0.86	0.1	2.2	0.064	0.019
PUNISHED WOMAN LAKE	5	09-Mar-89	830	GRAB	BOTTOM	30	31		11.3		150		7.53	75.8	212	195	17	0.67	0.8	2	0.312	0.207
PUNISHED WOMAN LAKE	5	09-Mar-89	830	GRAB	SURFACE	31	31	2	11.3		160		7.56	97.2	269	233	36	0.68	0.7	2.01	0.278	0.159
PUNISHED WOMAN LAKE	5	24-Apr-89	915	GRAB	SURFACE	52	52	2	9.3		10		8.06	141	340	314	26	0.02	0.1	1.11	0.098	0.005
PUNISHED WOMAN LAKE	5	24-Apr-89	915	GRAB	BOTTOM	53	52		9.1		10		8.11	141	337	312	25	0.02	0.1	1.09	0.068	0.005
PUNISHED WOMAN LAKE	5	09-May-89	900	GRAB	SURFACE	47	54	2.2	11		10		8.43	190	385	325	60	0.02	0.1	0.9	0.047	0.011
PUNISHED WOMAN LAKE	5	09-May-89	900	GRAB	BOTTOM	47	54		10.6		10		8.46	151	382	323	59	0.02	0.1	0.83	0.068	0.016
PUNISHED WOMAN LAKE	5	24-May-89	930	GRAB	SURFACE	64	64	1.9	8.2		10		8.34	180	418	331	87	0.02	0.1	0.8	0.115	0.018
PUNISHED WOMAN LAKE	5	24-May-89	930	GRAB	BOTTOM	63	64		8.7		10		8.25	162	417	331	86	0.02	0.1	0.69	0.081	0.012
PUNISHED WOMAN LAKE	5	14-Jun-89	1000	GRAB	S	54	49	5.5	9.6		40	510	8.31	165	444	364	80	0.02	0.10	0.85	0.115	0.005
PUNISHED WOMAN LAKE	5	14-Jun-89	1000	GRAB	B	54	49		10.0		10	509	8.28	165	442	363	79	0.02	0.10	0.87	0.119	0.005
PUNISHED WOMAN LAKE	5	27-Jun-89	720	GRAB	S	65	56	2.0	9.0		10	474	8.53	238	371	360	11	0.03	0.10	1.09	0.071	0.005
PUNISHED WOMAN LAKE	5	27-Jun-89	720	GRAB	B	64	56	0.0	9.1	1.0	10	490	8.54	153	374	365	9	0.03	0.10	1.31	0.105	0.005
PUNISHED WOMAN LAKE	5	06-Jul-89	1330	GRAB	B	76	82		8.8		10	444	8.95	126	352	324	28	0.03	0.10	0.93	0.066	0.005
PUNISHED WOMAN LAKE	5	06-Jul-89	1330	GRAB	S	75	82	2.0	9.7		10	439	8.96	135	350	322	28	0.03	0.10	0.95	0.065	0.005
PUNISHED WOMAN LAKE	5	20-Jul-89	830	GRAB	B	+ 68	69		9.8		10	433	9.06	121	355	246	109	-0.47	0.10	1.22	0.108	0.005
PUNISHED WOMAN LAKE	5	20-Jul-89	830	GRAB	S	+ 69	69	1.5	9.7		10	430	9.05	121	352	255	97	-0.49	0.10	1.25	0.098	0.005
PUNISHED WOMAN LAKE	5	08-Aug-89	715	GRAB	S	64	57	1.3	9.4		10	400	8.94	105	367	360	7	0.05	0.10	1.42	0.119	0.016
PUNISHED WOMAN LAKE	5	08-Aug-89	715	GRAB	B	63	57		8.9		10	400	9.01	104	359	272	87	0.05	0.10	1.47	0.119	0.013
PUNISHED WOMAN LAKE	5	31-Aug-89	1150	GRAB	B	66	63		9.3		220	390	9.23	102	331	275	56	0.07	0.10	1.34	0.095	0.005
PUNISHED WOMAN LAKE	5	31-Aug-89	1150	GRAB	S	65	63	1.8	8.7		2	398	9.24	103	331	272	59	0.06	0.10	1.24	0.095	0.007
PUNISHED WOMAN LAKE	5	11-Sep-89	830	GRAB	S	53	43	1.5	10.0		10	408	9.06	113	344	292	52	0.04	0.10	1.21	0.108	0.009
PUNISHED WOMAN LAKE	5	11-Sep-89	830	GRAB	B	51	43		9.9		10	410	9.04	113	374	290	84	0.05	0.10	1.21	0.166	0.005
PUNISHED WOMAN LAKE	5	28-Sep-89		GRAB	S	52	55	1.0	10.9		10	424	8.78	119	341	276	65	0.03	0.10	1.10	0.129	0.007
PUNISHED WOMAN LAKE	5	28-Sep-89	915	GRAB	B	52	55		10.5		10	429	8.55	117	348	280	68	0.03	0.10	1.58	0.122	0.005
PUNISHED WOMAN LAKE	5	18-Oct-89	1100	GRAB	S	41	38	1.9	12.3		10	471	8.52	138	373	330	43	0.03	0.10	0.70	0.083	0.005
PUNISHED WOMAN LAKE	5	18-Oct-89		GRAB	B	41	38		12.4		10	466	8.52	136	382	333	49	0.02	0.10	0.69	0.093	0.005

8255 Congdon Boulevard
Duluth, Minnesota 55804
(218) 525-6462
October 19, 1988

Punished Woman's Lake Association
P.O. Box 57
South Shore, South Dakota 57063-0057

Dear Lake Association:

Please find enclosed my analyses of eight phytoplankton samples from Punished Woman's Lake, South Dakota, collected on August 10, 23, 1988, and September 13, 26, 1988. If you would like the data presented differently or desire more information concerning blue-green algae or a particular species of algae please feel free to ask.

Sincerely,

Keith E. Camburn

Punished Woman's Lake, South Dakata

Sites 4; August 10, 23, 1988; September 13, 26, 1988

At this sampling site the total units/ml of phytoplankton were 57401, 48395, 53259, and 37615, respectively, on August 10, 23, 1988, and September 13, 26, 1988. The most abundant algae were the blue-greens Aphanocapsa and Merismopedia and the diatom Melosira granulata. On each sampling date the most common alga was Aphanocapsa, which is a common coccoid blue-green encountered in lakes.

Sites 5; August 10, 23, 1988; September 13, 26, 1988

At this sampling site the total units/ml of phytoplankton were 42058, 49863, 43660, and 47539, respectively, on August 10, 23, 1988, and September 13, 26, 1988. As at Site 4, the most common phytoplankton were the blue-greens Aphanocapsa and Merismopedia. The diatom Melosira granulata which was common on all four sampling dates at Site 4 occurred at Site 5 only on September 13th and 26th. Several factors must be kept in mind when discussing the ecological significance of the units/ml of a blue-green alga such as Aphanocapsa. Aphanocapsa is a colonial blue-green alga and units/ml are determined by enumerating colonies some of which contain a few hundred cells while others may contain thousands of cells. Therefore, higher or lower units/ml between dates or sampling sites may be attributable to consistently smaller or larger colonies. Wind currents may also play a role in the accumulation of algae in a particular region of the lake. Only through repeated sampling over a period of time can it be ascertained if differences exist in the phytoplankton between the two sampling sites at Punished Woman's Lake.

Conclusion:

The phytoplankton present at the two sampling sites on August 10, 23, 1988, and September 13, 26, 1988, appears to be typical for this region of the country. Aphanocapsa and Merismopedia are common and widespread.blue-green algae which are frequently encountered in eutrophic lakes. The diatom Melosira granulata is likewise a widespread eutrophic taxon. It is interesting to note the absence of Melosira granulata at Site 5 on August 10th and 23rd.

Punished Woman's Lake, South Dakota

Site 4

	Aug 10	Aug 23	Sept 13	Sept 26
Blue-Green Algae				
Anabaena	941	159	178	-
Aphanizomenon flos-aquae	376	478	-	127
Aphanocapsa	33123	34385	27516	19189
Aphanothece	188	-	-	127
Chroococcus	565	1592	533	254
Dactylococcopsis	2070	955	178	-
Lyngbya	-	-	-	-
Merismopedia	3764	1274	3195	254
Green Algae				
Actinastrum	565	-	-	-
Crucigenia	376	-	-	-
Pediastrum	753	159	888	127
Scenedesmus	753	637	1420	1525
Schroederia	-	-	-	-
Staurastrum	188	-	-	-
Tetraedron	376	159	355	1144
Green Algae (other)	4329	1433	2663	2033
Diatoms				
Melosira granulata	4329	2229	12782	2796
Nitzschia	-	-	178	254
Rhizosolenia	753	-	-	-
Synedra	-	159	533	-
Diatoms (centric)	-	-	-	-
Diatoms (other)	188	-	-	-
Cryptomonads				
Cryptomonas	188	478	-	-
Dinoflagellates				
Ceratium	-	-	-	-
(other)	-	-	-	-
Algae (flagellates)	-	-	-	-
(other)	3576	4298	2840	9785
Total	57401	48395	53259	37615

Punished Woman's Lake, South Dakota

Site 5

	Aug 10	Aug 23	Sept 13	Sept 26
Blue-Green Algae				
Anabaena	-	660	-	158
Aphanizomenon flos-aquae	838	165	-	-
Aphanocapsa	25850	34014	23764	21953
Aphanothece	-	-	143	158
Chroococcus	2934	1156	429	316
Dactylococcopsis	559	330	573	474
Lyngbya	-	165	-	-
Merismopedia	2515	660	2147	1895
Green Algae				
Actinastrum	140	-	-	-
Crucigenia	699	165	429	158
Pediastrum	-	660	286	-
Scenedesmus	978	330	1145	2211
Schroederia	140	-	-	-
Staurastrum	-	-	-	-
Tetraedron	279	330	429	2685
Green Algae (other)	1397	1321	1288	1106
Diatoms				
Melosira granulata	-	-	7874	3159
Nitzschia	-	165	-	158
Rhizosolenia	140	330	-	-
Synedra	-	-	-	-
Diatoms (centric)	-	-	-	-
Diatoms (other)	-	165	286	-
Cryptomonads				
Cryptomonas	699	1156	-	-
Dinoflagellates				
Ceratium	-	-	143	-
(other)	-	165	-	-
Algae (flagellates)	-	-	-	-
(other)	4890	7926	4724	13108
Total	42058	49863	43660	47539

APPENDIX C

AGNPS Model Report

NOTE: The AGNPS model uses U.S. customary units rather than metric units and the computer print-outs reflect this fact. Those persons desiring metric units may do so by using the following conversion equations.

1 ppm = 1 mg/l
1 lb/acre = 1.12 Kg/Ha
1 Acre = .4047 Hectares
1 Inch = 2.54 Centimeters
1 Ton = 907.18 Kilograms
1 ton/acre = 2,243.6 Kg/Ha

The Agricultural Non-Point Source Pollution Model (AGNPS)

Background

The Agricultural Non-Point Source Pollution Model (AGNPS) developed by Dr. Robert A. Young at the Agriculture Research Service Laboratory (ARS) in Morris, Minnesota, is being used by DENR to evaluate watershed management options. The AGNPS computer simulation model has the capability to predict the effect of BMP implementation on the sediment, phosphorus, and nitrogen output of the watershed. The model simulates nutrient and sediment runoff during a single storm event using land-use practices and the physical characteristics of the land area (cell) in question. Twenty-one cell parameters and 10 feedlot parameters are required to quantitatively describe each watershed cell and feedlot for the input datafile of the model. Critical cells and feedlots may then be selected for data management based on their nutrient and sediment output obtained on execution of the initial computer run.

The model output predicts watershed runoff volume and peak runoff rate with estimates of upland/channel erosion and delivered sediment as well as nutrient and chemical oxygen demand (COD) transport for any cell or the entire watershed. Estimates of dissolved and sediment-associated phosphorus and nitrogen are given in units of concentration (ppm) and mass (lb/acre).

Following this evaluation, coordination with State and Federal agricultural agencies is solicited to verify the critical nature of the identified cells and the efficacy of selected control methods such as fertilizer/animal waste management and conservation tillage among others. For those areas targeted as critical, the owner/operators are contacted to request their voluntary participation in the control program.

Procedure

The Punished Woman's Lake watershed of 12,280 acres was divided into 307 square 40-acre cells (Figure 5) by superimposing a grid on a USGS topographic map (scale 1:2400) in accordance with AGNPS analysis procedures (Young et al., 1986). In addition, field surveys indicated the presence of 12 feeding operations (feedlots) in the Punished Woman's Lake drainage area.

The AGNPS computer program requires collection of 21 watershed cell parameters and 10 feedlot parameters. Cell parameters describe the physical features (soil types, hydrology, topography, etc.), and farming practices and other land uses for each 40-acre cell in the watershed. Feedlot parameters include the dimension of various parts of a feeding operation, soil types and vegetative cover, characteristics of runoff, and the type and number of animals present. The present AGNPS program (version 3.60 P.C.) contains a subroutine for analyzing runoff at the point of feedlot effluent channeling, and a feedlot rating output (rating number) which allows comparison of the potential impact of each feedlot on the watershed. In general, feedlots with rating numbers of 40 or higher can be considered to have the most significant impact on a scale of 0 to 100.

The type of storm event selected for this computer simulation was based on estimates of average annual soil losses in the watershed as previously determined by SCS. The storm event selected was a 5-year, 24 hour rainstorm with a rainfall of 3.2 inches and a storm energy intensity (EI) of 95 to reflect average annual erosion rates.

Sources of information for cell parameters and feedlot parameters included SCS personnel, farmer interviews, topographic maps, visual observations, ASCS records, county survey maps, and reference tables contained in Young et al. (1986) and SCS Technical Guides for South Dakota.

Results

The output of the initial computer run is shown in Table 6 for the waterflow pattern in the watershed as designated by arrows in Figures 5 and 6. Because the present computer model requires routing water flow through the lake to the spillway (there can be only one watershed outlet in the model), nutrient mass and concentration and particularly sediment loads, are diluted. However, nutrient and sediment values can be obtained for all the lake tributary inlets in undiluted form with this model, although nutrient concentrations in parts per million (ppm) appear in the output to the nearest unit only.

When feedlots in the drainage (12) were included in the input data the result was a noticeable increase in nutrient values at the watershed outlet (spillway) despite the masking effect produced by the lake (Table 7). This result suggests that livestock feeding operations in the drainage were exerting some influence on lake water quality. Results of the feedlot analysis subroutine indicate, moreover, that feedlots located at cell numbers 133, 193, and 300 can be expected to have the greatest effect with rating numbers of 44, 30, and 53, respectively (Table 8). The location of those feedlots in the watershed is shown in Figure 7.

Nutrient and sediment inputs to Punished Woman's Lake via its major and minor tributaries are shown in Table 9 (feedlots deleted). Feedlot and watershed contributions of soluble nutrients are presented in Table 10. To obtain nutrient mass and concentration attributable to watershed feeding operations the values in Table 9 (either lbs/acre or ppm) are subtracted from corresponding values in Table 10. Moderately sized feeding operations export little sediment in runoff and therefore negligible levels of sediment-associated nutrients (Tables 9 and 10). Table 9 indicates that watershed acreages are contributing an average (weighted) of 1.68 lbs/acre of nitrogen and 0.69 lbs/acre of phosphate to the lake along with 3162 tons total of sediment. The table shows that the majority of nutrients contributed, particularly phosphates, are sediment-associated and therefore are very likely derived from eroding watershed acreages.

Table 11 presents the sediment yields of 32 watershed cells (1280 acres) that show the highest erosions rates (tons/acre) in the drainage as well as a second group of 12 cells (480 acres) that produce lesser but still considerable sediment yields (>60 tons). Moreover, field data indicate that virtually all of the above acreages are subject to relatively high rates of fertilization (100-200 lbs/ac. of nitrogen and 40-80 lbs/ac. of phosphorus). Figures 5 and 8 locate the above cells in the lake watershed. It is highly likely that a large percentage of applied nutrients is lost during the erosion process and that they along with the eroded sediments enter Punished Woman's Lake during periods of runoff (Tables 12 and 13).

The first 32 listed watershed cells in Table 11 should be given priority for a on-the-ground inspection by qualified personnel to confirm the existence of erosion problems indicated by the computer model. If such are clearly in evidence, arrangements should be made for the application of selected Best Management Practices.

Acreages surrounding Punished Woman's Lake can be expected to exert a disproportionate influence on lake water quality due to their close proximity to the lakeshore. Sediment analysis indicated that most of those acreages, except for cells #241 and #242, had relatively moderate erosion and nutrient export rates (Tables 14 and 15).

The effect of urban runoff from South Shore on nutrient transport was roughly estimated by applying a low level of fertilization (50 lbs/ac. N and 20 lbs/ac. P) to urban cells #260 and #261 (Figure 5). The results in Table 16 indicate a considerable increase in nutrient export to the lake compared to background nutrient levels in Table 15.

An attempt to determine the effect of the larger feeding operations on nutrient levels was made by deleting the output of the feedlots mentioned previously (feedlots #133 and #193 upstream of inlet cell #220; feedlot #300 upstream of inlet cell #227; and, in addition, feedlot #256 upstream of inlet cell #242). Table 17 shows that the largest reductions in soluble nutrient levels occur at lake inlet cells #242 and #227 when outputs of feedlots at cells #256 and #300, respectively, are deleted (compare Table 17 with Table 10). This procedure simulates the effect of installing animal waste management systems for feedlots #256 and #300. Decreases in nutrients at the remaining lake inlet at cell #220 were more moderate but should be considered in efforts to reduce watershed nutrient loads to Punished Woman's Lake.

Recommendation

The following 40-acre cells and feeding operations should be prioritized for a ground survey to confirm any erosion and sediment/nutrient export problems which may be responsible for contributing significant levels of sediments and nutrients to Punished Woman's Lake:

Cell #	Cell Location	County
2	T120N, R51W, SEC. 19, SW4, NW4	Grant
3	T120N, R51W, SEC. 19, SW4, NE4	Grant
12	T120N, R51W, SEC. 30, NE4, NW4	Grant
17	T120N, R51W, SEC. 28, NW4, NW4	Grant
23	T120N, R51W, SEC. 30, NE4, SW4	Grant
35	T120N, R51W, SEC. 30, SE4, NW4	Grant
47	T120n, R51W, SEC. 30, SE4, SW4	Grant
70	T120N, R51W, SEC. 34, NW4, NW4	Grant
81	T120N, R51W, SEC. 32, NE4, SE4	Grant
86	T120N, R51W, SEC. 34, NW4, SW4	Grant
93	T120N, R51W, SEC. 32, SE4, NE4	Grant
95	T120N, R51W, SEC. 33, SW4, NE4	Grant
100	T120N, R51W, SEC. 34, SE4, NW4	Grant
101	T120N, R51W, SEC. 34, SE4, NE4	Grant
102	T120N, R51W, SEC. 33, SW4, SW4	Grant
109	T120N, R51W, SEC. 34, SE4, SE4	Grant
111	T120N, R51W, SEC. 35, SW4, SE4	Grant
127	T119N, R51W, SEC. 3, NE4, SW4	Codington
128	T119N, R51W, SEC. 3, NE4, SE4	Codington
136	T119N, R51W, SEC. 3, SE4, NW4	Codington
137	T119N, R51W, SEC. 3, SE4, NE4	Codington
139	T119N, R51W, SEC. 4, SW4, SW4	Codington
148	T119N, R51W, SEC. 8, NE4, NE4	Codington
156	T119N, R51W, SEC. 10, NE4, NE4	Codington
178	T119N, R51W, SEC. 10, SW4, NE4	Codington
195	T119N, R51W, SEC. 18, NE4, NE4	Codington
207	T119N, R51W, SEC. 18, NE4, SE4	Codington
239	T119N, R51W, SEC. 17, SE4, SE4	Codington
241	T119N, R51W, SEC. 16, SW4, SE4	Codington
242	T119N, R51W, SEC. 16, SE4, SW4	Codington
249	T119N, R51W, SEC. 19, NE4, NE4	Codington
275	T119N, R51W, SEC. 19, SE4, NE4	Codington
287	T119N, R51W, SEC. 20, SW4, SW4	Codington
298	T119N, R51W, SEC. 29, NE4, NE4	Codington

Cell #	Feedlot Location	County
256	T119N, R51W, SEC. 21, NE4, NW4	Codington
300	T119N, R51W, SEC. 28, NW4, NE4	Codington
133	T119N, R51W, SEC. 4, SE4, NE4	Codington
193	T119N, R51W, SEC. 10, SE4, SE4	Codington

Figure 5. Punished Woman's Lake watershed divided into 40-acre cells.

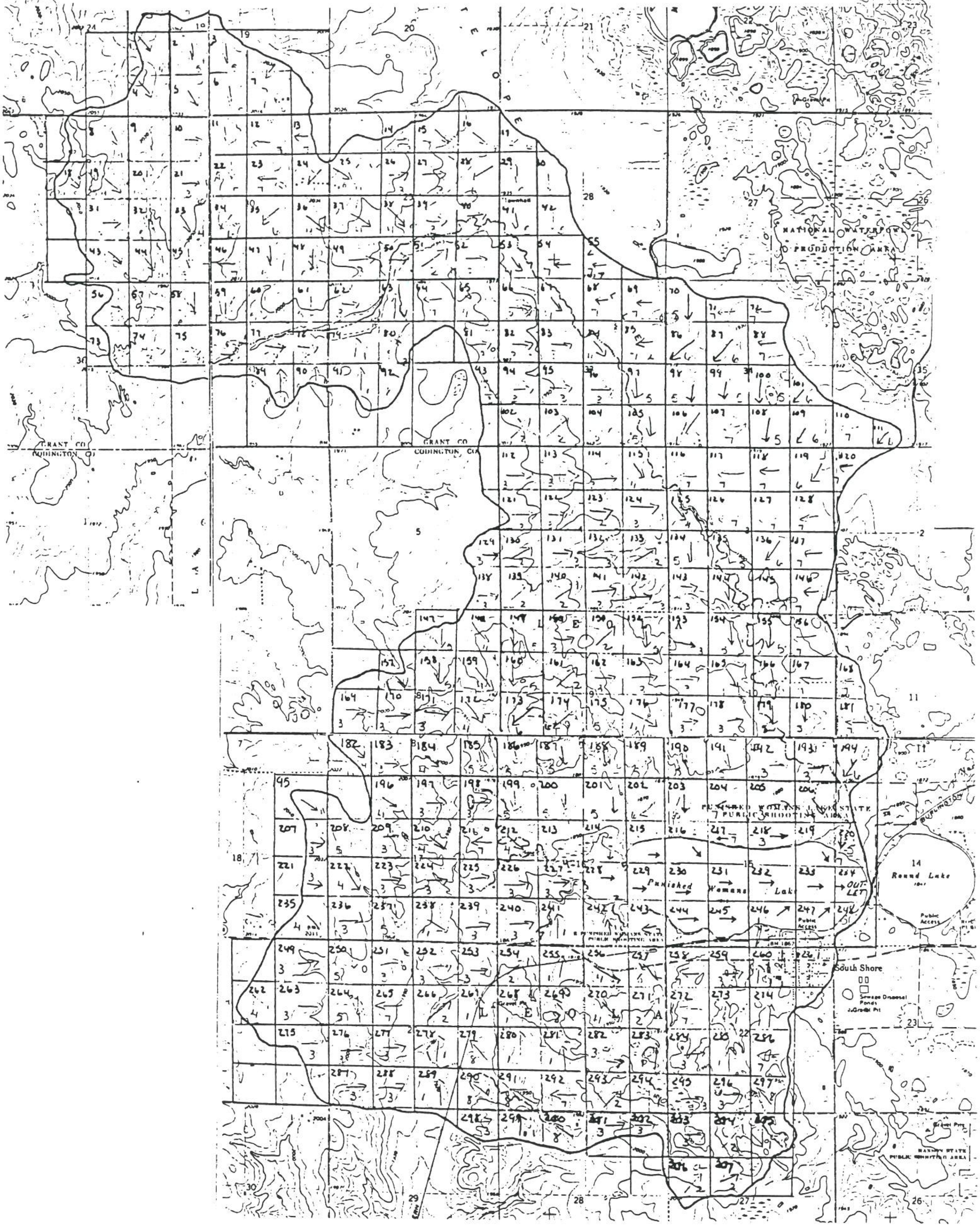

Table 6. AGNPS output for the Punished Woman's Lake watershed without feedlots.

Watershed Summary

Watershed Studied	PUNISHED WOMAN'S LAKE AGNPS	
The area of the watershed is	12280	acres
The area of each cell is	40.00	acres
The characteristic storm precipitation is	3.20	inches
The storm energy-intensity value is	95	

Values at the Watershed Outlet

Cell number	234	000
Runoff volume	1.3	inches
Peak runoff rate	2035	cfs
Total Nitrogen in sediment	0.73	lbs/acre
Total soluble Nitrogen in runoff	0.59	lbs/acre
Soluble Nitrogen concentration in runoff	1.98	ppm
Total Phosphorus in sediment	0.37	lbs/acre
Total soluble Phosphorus in runoff	0.08	lbs/acre
Soluble Phosphorus concentration in runoff	0.28	ppm
Total soluble chemical oxygen demand	17.48	lbs/acre
Soluble chemical oxygen demand concentration in runoff	59	ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.08	0.00	97	8	526.48	0.08	959.4
SILT	0.11	0.00	43	4	306.83	0.05	559.1
SAGG	0.70	0.00	5	0	251.58	0.04	458.4
LAGG	0.41	0.00	0	0	0.34	0.00	0.6
SAND	0.09	0.00	0	0	0.11	0.00	0.2
TOTAL	1.39	0.00	12	1	1085.33	0.16	1977.8

Figure 6. Punished Woman's Lake watershed drainage pattern.

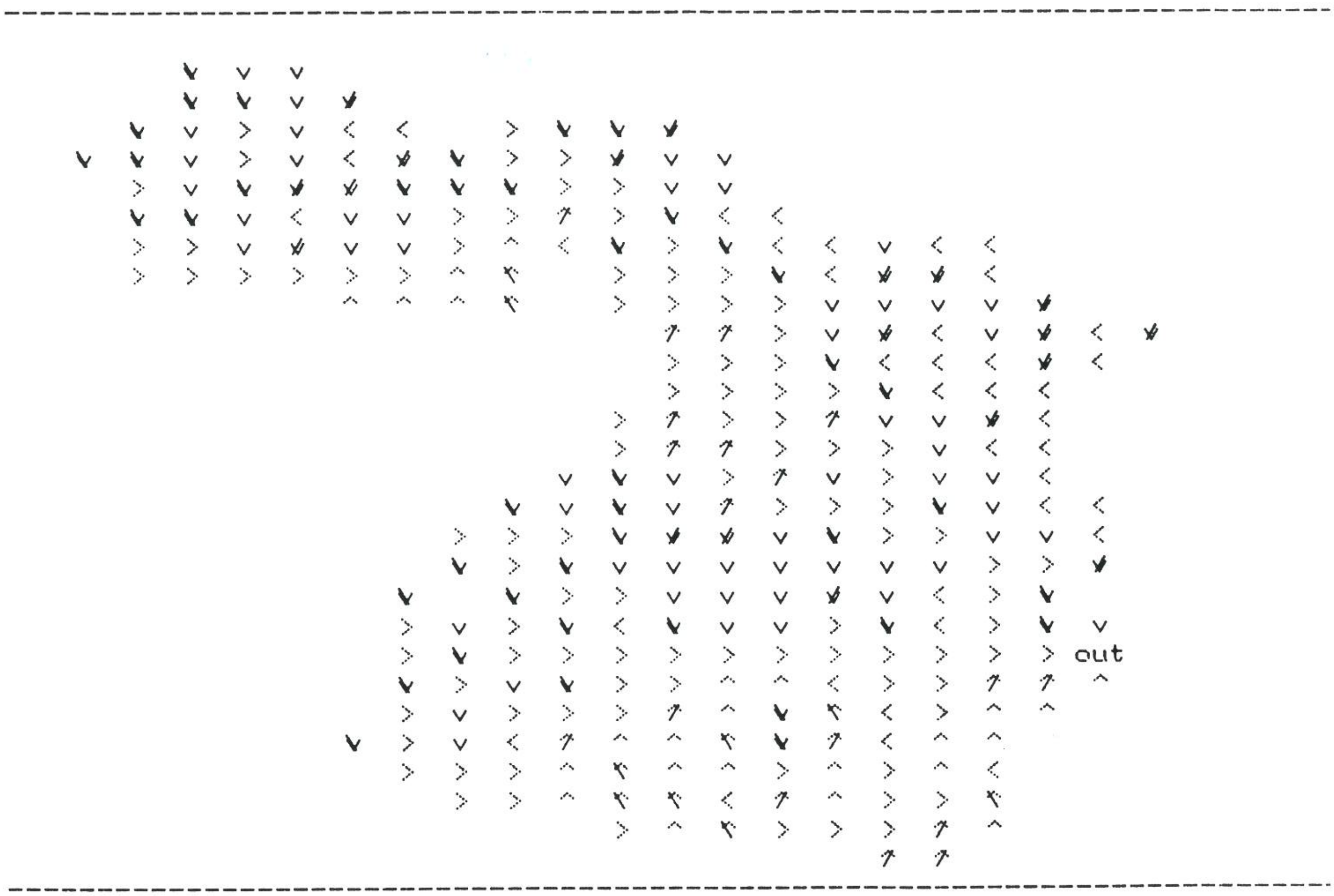

Table 7. AGNPS output for the Punished Woman's Lake watershed with all feedlots included.

Watershed Summary

Watershed Studied	PUNWOM6F.DAT-12FEEDLOTS	
The area of the watershed is	12280	acres
The area of each cell is	40.00	acres
The characteristic storm precipitation is	3.20	inches
The storm energy-intensity value is	95	

Values at the Watershed Outlet

Cell number	234	000
Runoff volume	1.3	inches
Peak runoff rate	2036	cfs
Total Nitrogen in sediment	0.74	lbs/acre
Total soluble Nitrogen in runoff	0.67	lbs/acre
Soluble Nitrogen concentration in runoff	2.26	ppm
Total Phosphorus in sediment	0.37	lbs/acre
Total soluble Phosphorus in runoff	0.10	lbs/acre
Soluble Phosphorus concentration in runoff	0.35	ppm
Total soluble chemical oxygen demand	18.70	lbs/acre
Soluble chemical oxygen demand concentration in runoff	63	ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.08	0.00	97	8	532.24	0.08	970.2
SILT	0.11	0.00	43	4	310.50	0.05	566.0
SAGG	0.71	0.00	5	0	252.12	0.04	459.6
LAGG	0.42	0.00	0	0	0.34	0.00	0.6
SAND	0.09	0.00	0	0	0.11	0.00	0.2
TOTAL	1.41	0.00	12	1	1095.30	0.16	1996.6

Table 8. AGNPS analysis of feedlots in the Punished Woman's Lake watershed.

Feedlot Analysis

Cell # 7 000

Nitrogen concentration (ppm)	5.320
Phosphorus concentration (ppm)	1.059
COD concentration (ppm)	42.725
Nitrogen mass (lbs)	46.619
Phosphorus mass (lbs)	9.281
COD mass (lbs)	374.404
Animal feedlot rating number	4

Feedlot Analysis

Cell # 25 000

Nitrogen concentration (ppm)	8.123
Phosphorus concentration (ppm)	2.354
COD concentration (ppm)	205.027
Nitrogen mass (lbs)	33.376
Phosphorus mass (lbs)	9.673
COD mass (lbs)	842.402
Animal feedlot rating number	27

Feedlot Analysis

Cell # 48 000

Nitrogen concentration (ppm)	7.872
Phosphorus concentration (ppm)	1.312
COD concentration (ppm)	39.358
Nitrogen mass (lbs)	44.327
Phosphorus mass (lbs)	7.388
COD mass (lbs)	221.637
Animal feedlot rating number	0

Feedlot Analysis

Cell # 93 000

Nitrogen concentration (ppm)	13.750
Phosphorus concentration (ppm)	6.426
COD concentration (ppm)	288.687
Nitrogen mass (lbs)	48.926
Phosphorus mass (lbs)	22.864
COD mass (lbs)	1027.232
Animal feedlot rating number	29

Table 8. Continued.

Feedlot Analysis

Cell # 105 000

Nitrogen concentration (ppm)	7.434
Phosphorus concentration (ppm)	1.938
COD concentration (ppm)	163.522
Nitrogen mass (lbs)	7.291
Phosphorus mass (lbs)	1.901
COD mass (lbs)	160.371

Animal feedlot rating number 4

Feedlot Analysis

Cell # 133 000

Nitrogen concentration (ppm)	39.936
Phosphorus concentration (ppm)	7.011
COD concentration (ppm)	490.683
Nitrogen mass (lbs)	241.320
Phosphorus mass (lbs)	42.366
COD mass (lbs)	2965.021

Animal feedlot rating number 44

Feedlot Analysis

Cell # 144 000

Nitrogen concentration (ppm)	90.545
Phosphorus concentration (ppm)	23.955
COD concentration (ppm)	1554.545
Nitrogen mass (lbs)	57.511
Phosphorus mass (lbs)	15.215
COD mass (lbs)	987.384

Animal feedlot rating number 28

Feedlot Analysis

Cell # 145 000

Nitrogen concentration (ppm)	39.313
Phosphorus concentration (ppm)	8.663
COD concentration (ppm)	829.240
Nitrogen mass (lbs)	17.357
Phosphorus mass (lbs)	3.825
COD mass (lbs)	366.109

Animal feedlot rating number 15

Table 8. Continued.

Feedlot Analysis

Cell # 166 000

Nitrogen concentration (ppm)	19.462
Phosphorus concentration (ppm)	5.533
COD concentration (ppm)	502.307
Nitrogen mass (lbs)	18.382
Phosphorus mass (lbs)	5.226
COD mass (lbs)	474.415
Animal feedlot rating number	18

Feedlot Analysis

Cell # 193 000

Nitrogen concentration (ppm)	25.838
Phosphorus concentration (ppm)	12.072
COD concentration (ppm)	558.986
Nitrogen mass (lbs)	50.010
Phosphorus mass (lbs)	23.365
COD mass (lbs)	1081.933
Animal feedlot rating number	30

Feedlot Analysis

Cell # 256 000

Nitrogen concentration (ppm)	27.218
Phosphorus concentration (ppm)	5.961
COD concentration (ppm)	280.200
Nitrogen mass (lbs)	73.506
Phosphorus mass (lbs)	16.100
COD mass (lbs)	756.715
Animal feedlot rating number	24

Feedlot Analysis

Cell # 300 000

Nitrogen concentration (ppm)	61.331
Phosphorus concentration (ppm)	12.250
COD concentration (ppm)	1076.444
Nitrogen mass (lbs)	306.908
Phosphorus mass (lbs)	61.299
COD mass (lbs)	5386.698
Animal feedlot rating number	53

Figure 7. Feedlots (boxed) and critical feedlots (circled) in the Punished Woman's Lake watershed.

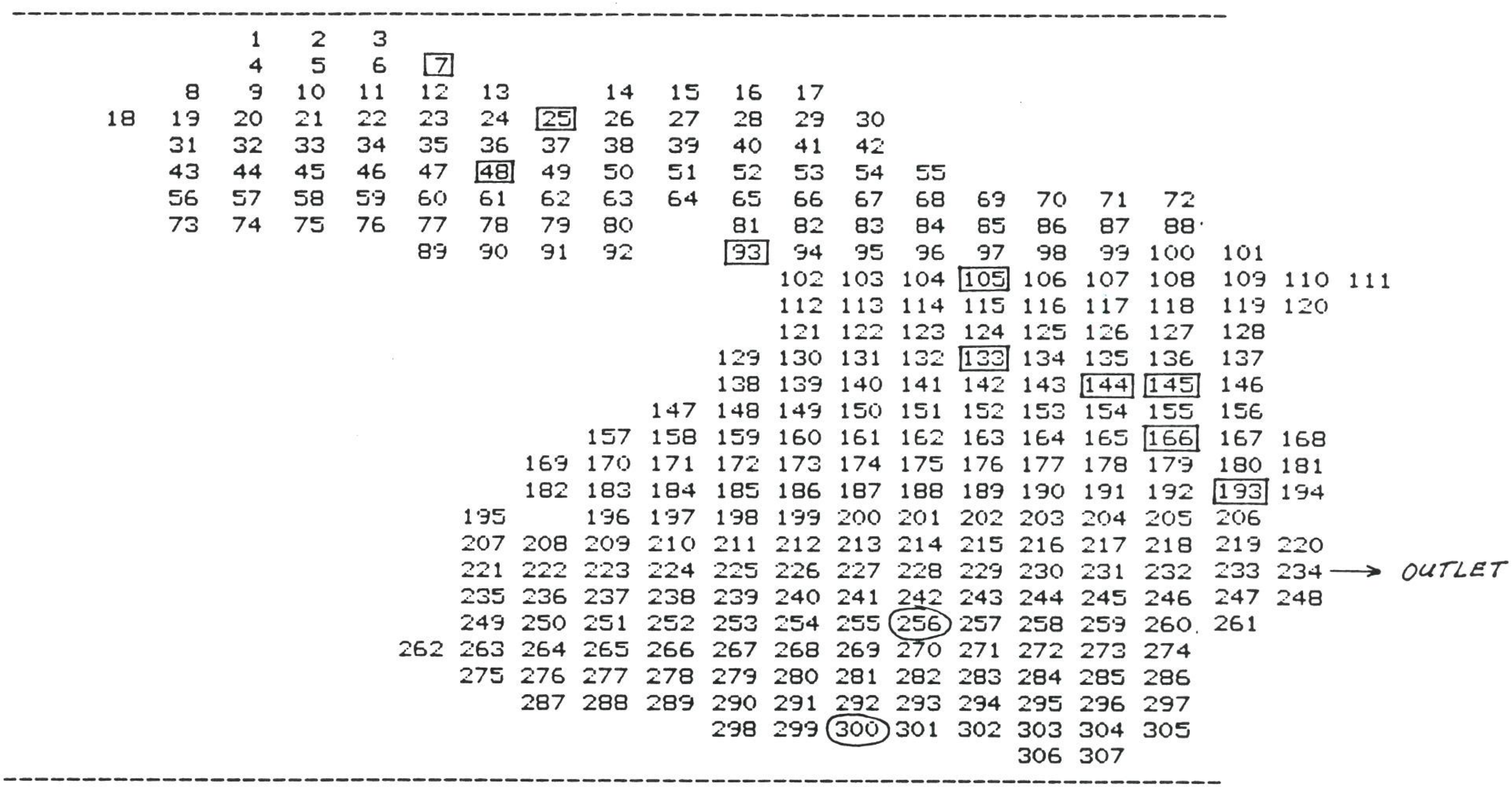

Table 9. Sediment yield and nutrient mass/concentration at Punished Woman's Lake tributary inlets (feedlots deleted).

Condensed Soil Loss

Cell Num	Div	Drainage Area (acres)	RUNOFF Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	SEDIMENT Generated Above (tons)	Generated Within (tons)	Yield (tons)	Depo (%)
201	000	120	0.93	74.2	133	0.64	17.36	25.72	27.50	36
202	000	80	0.44	73.2	84	0.22	2.67	8.88	5.78	50
203	000	200	1.21	79.2	215	0.22	32.85	8.88	29.80	29
217	000	40	0.73	0.0	73	0.69	0.00	27.74	17.30	38
218	000	40	0.73	0.0	73	0.69	0.00	27.74	17.30	38
220	000	6880	1.84	99.1	1425	0.05	1832.13	1.91	1726.23	6
227	000	3080	2.08	97.9	1206	0.05	1136.96	1.91	1063.58	7
242	000	480	0.98	93.4	348	2.57	115.50	102.89	155.88	29
260	000	680	2.26	89.0	421	0.07	123.56	2.69	116.56	8
261	000	40	2.26	0.0	170	0.07	0.00	2.69	2.43	10

Nutrient Analysis
N I T R O G E N

Cell Num	Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220	000	6880	0.28	1.05	0.37	0.70	3
227	000	3080	0.28	1.35	0.43	0.48	2
242	000	480	6.74	1.29	1.25	0.33	1
260	000	680	0.37	0.77	0.47	0.24	1
261	000	40	0.37	0.34	0.47	0.47	1

Nutrient Analysis
P H O S P H O R U S

Cell Num	Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220	000	6880	0.14	0.52	0.02	0.11	0
227	000	3080	0.14	0.68	0.02	0.06	0
242	000	480	3.37	0.64	0.24	0.03	0
260	000	680	0.18	0.39	0.03	0.01	0
261	000	40	0.18	0.17	0.03	0.03	0

Table 10. Nutrient mass and concentration at five Punished Woman's Lake tributary inlets with all feedlots included.

Nutrient Analysis
NITROGEN

Cell Num Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220 000	6880	0.28	1.06	0.37	0.79	3
227 000	3080	0.28	1.35	0.43	0.60	2
242 000	480	6.74	1.29	1.25	0.56	2
260 000	680	0.37	0.77	0.47	0.24	1
261 000	40	0.37	0.34	0.47	0.47	1

Nutrient Analysis
PHOSPHORUS

Cell Num Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220 000	6880	0.14	0.53	0.02	0.13	1
227 000	3080	0.14	0.68	0.02	0.09	0
242 000	480	3.37	0.64	0.24	0.08	0
260 000	680	0.18	0.39	0.03	0.01	0
261 000	40	0.18	0.17	0.03	0.03	0

Table 11. Soil loss and sediment generated in selected cells of the Punished Woman's Lake watershed.

Condensed Soil Loss

Cell Num	Div	RUNOFF Drainage Area (acres)	Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	SEDIMENT Generated Above (tons)	Within (tons)	Yield (tons)	Depo (%)
2	000	40	1.04	0.0	81	4.29	0.00	171.80	91.63	47
3	000	40	1.27	0.0	96	4.29	0.00	171.80	106.36	38
12	000	80	1.04	47.3	94	4.88	4.83	195.23	102.30	49
17	000	40	1.15	0.0	88	6.47	0.00	258.83	155.07	40
23	000	40	1.04	0.0	81	6.83	0.00	273.32	165.86	39
35	000	80	1.04	50.0	90	6.83	1.57	273.32	137.55	50
47	000	40	1.04	0.0	81	6.83	0.00	273.32	165.89	39
70	000	120	1.04	67.8	127	4.92	80.24	196.94	178.88	35
81	000	40	1.04	0.0	81	6.83	0.00	273.32	165.86	39
86	000	160	1.04	75.7	139	4.92	178.88	196.94	227.08	40
93	000	40	1.04	0.0	81	14.07	0.00	562.68	337.63	40
95	000	160	1.15	74.8	176	8.10	359.72	324.20	429.81	37
100	000	40	1.15	0.0	88	6.47	0.00	258.83	155.22	40
101	000	40	1.15	0.0	88	6.47	0.00	258.83	155.22	40
102	000	40	1.04	0.0	81	6.83	0.00	273.32	165.86	39
109	000	80	1.04	50.0	96	4.92	49.96	196.94	132.38	46
111	000	40	1.04	0.0	81	4.92	0.00	196.94	119.64	39
127	000	200	1.15	79.6	175	8.04	338.89	321.58	438.66	34
128	000	40	1.15	0.0	92	8.04	0.00	321.58	220.30	31
136	000	80	1.27	50.0	119	8.04	222.21	321.58	327.35	40
137	000	40	1.27	0.0	100	8.04	0.00	321.58	222.21	31
139	000	80	1.27	51.2	118	4.39	3.38	175.53	98.62	45
148	000	40	1.09	0.0	88	5.64	0.00	225.63	132.96	41
156	000	40	1.04	0.0	99	24.27	0.00	970.99	700.26	28
178	000	80	1.04	50.0	102	6.12	11.27	244.68	160.53	37
195	000	40	1.09	0.0	84	4.39	0.00	175.78	102.44	42
207	000	40	1.09	0.0	84	4.39	0.00	175.78	106.15	40
239	000	40	1.04	0.0	81	5.63	0.00	225.07	136.68	39
249	000	40	1.04	0.0	88	12.46	0.00	498.26	310.14	38
275	000	80	1.04	50.0	96	6.15	38.72	246.09	152.58	46
287	000	40	1.04	0.0	88	12.46	0.00	498.26	310.14	38
298	000	40	1.04	0.0	99	34.33	0.00	>999	883.64	36

Condensed Soil Loss

Cell Num	Div	RUNOFF Drainage Area (acres)	Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	SEDIMENT Generated Above (tons)	Within (tons)	Yield (tons)	Depo (%)
41	000	2800	1.04	98.7	923	2.12	426.69	84.65	466.03	9
71	000	80	1.04	52.6	93	2.12	64.59	84.65	80.24	46
118	000	240	1.15	82.5	197	3.03	365.63	121.28	327.27	33
119	000	120	1.15	65.5	108	2.78	107.01	111.15	118.59	46
120	000	80	1.15	47.4	90	2.78	119.64	111.15	107.01	54
147	000	40	1.09	0.0	84	3.13	0.00	125.38	73.11	42
154	000	6040	1.04	99.4	1522	2.31	1660.89	92.28	1647.14	6
155	000	80	1.04	50.0	86	1.68	700.26	67.02	439.22	43
235	000	40	1.04	0.0	81	1.70	0.00	67.82	41.37	39
241	000	1720	0.98	98.2	904	2.57	862.38	102.89	855.79	11
242	000	480	0.98	93.4	348	2.57	115.50	102.89	155.88	29
262	000	40	1.04	0.0	65	1.70	0.00	67.82	38.72	43

Figure 8. Primary (circled) and secondary (boxed) critical erosion cells (Table 6A) in the Punished Woman's watershed.

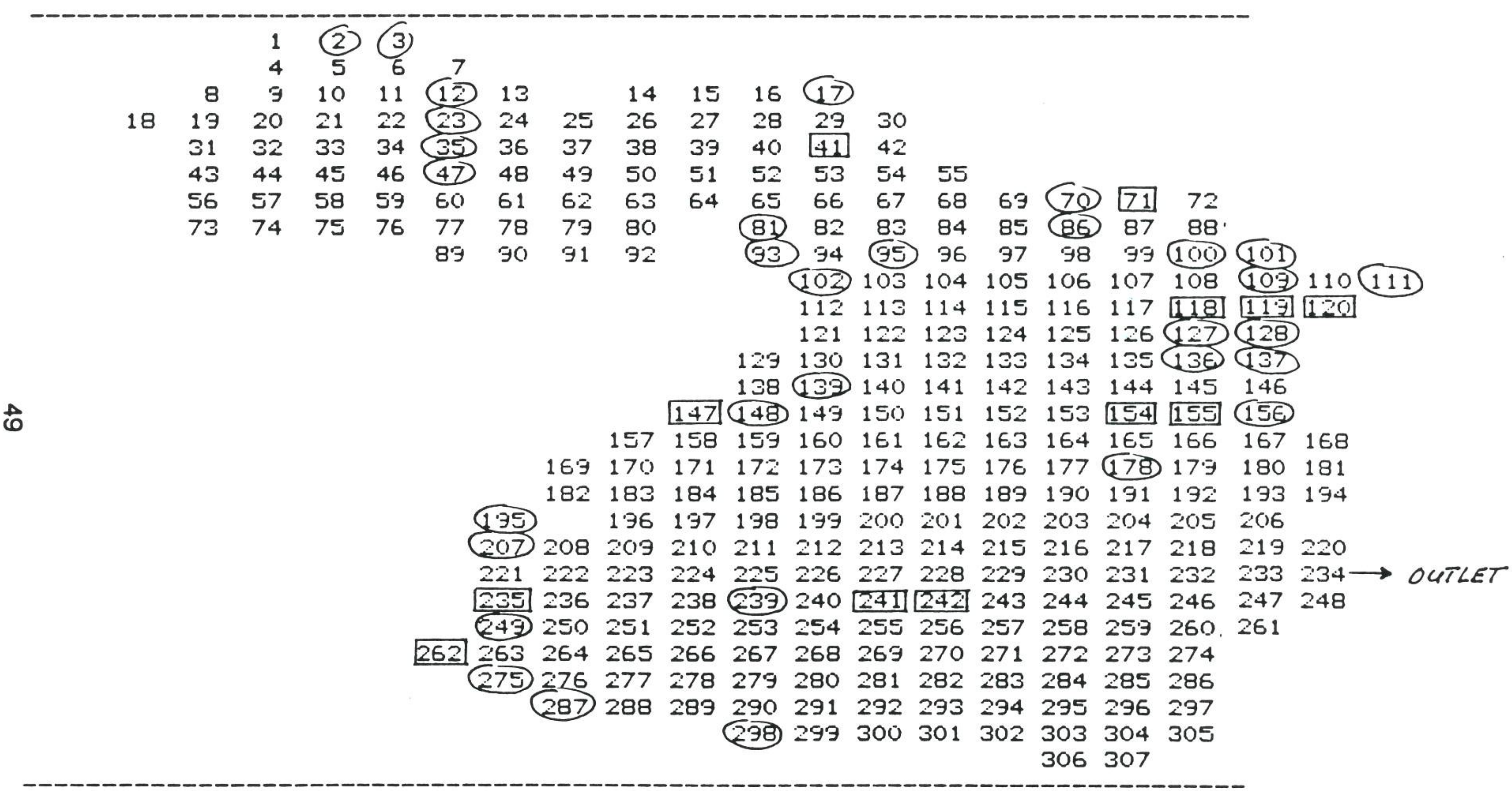

Table 12. Nitrogen output of critical erosion cells (Table 6A) in the Punished Woman's Lake watershed.

Nutrient Analysis
N I T R O G E N

Cell Num Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
2 000	40	10.15	6.14	0.40	0.40	2
3 000	40	10.15	6.92	0.89	0.89	3
12 000	80	11.25	3.85	0.70	0.83	4
17 000	40	14.09	9.35	0.48	0.48	2
23 000	40	14.72	9.87	0.99	0.99	4
35 000	80	14.72	4.88	0.99	0.60	3
47 000	40	14.72	9.87	0.99	0.99	4
70 000	120	11.32	4.35	0.99	1.40	6
81 000	40	14.72	9.87	0.99	0.99	4
86 000	160	11.32	4.19	1.78	1.50	6
93 000	40	26.23	17.43	0.70	0.70	3
95 000	160	16.87	6.97	1.60	0.89	3
100 000	40	14.09	9.36	0.73	0.73	3
101 000	40	14.09	9.36	0.73	0.73	3
102 000	40	14.72	9.87	0.99	0.99	4
109 000	80	11.32	4.73	1.78	1.78	8
111 000	40	11.32	7.60	1.78	1.78	8
127 000	200	19.28	6.82	0.66	0.81	3
128 000	40	19.28	14.25	0.66	0.66	3
136 000	80	19.28	11.23	0.81	0.81	3
137 000	40	19.28	14.34	0.81	0.81	3
139 000	80	10.33	3.74	1.52	0.89	3
148 000	40	12.63	8.27	1.44	1.44	6
156 000	40	46.67	35.93	0.88	0.88	4
178 000	80	15.49	6.35	0.88	0.77	3
195 000	40	10.34	6.71	1.44	1.44	6
207 000	40	10.34	6.91	1.44	1.44	6
239 000	40	12.60	8.46	0.99	0.99	4
249 000	40	23.80	16.29	0.99	0.99	4
275 000	80	13.53	5.30	0.99	0.99	4
287 000	40	23.80	16.29	1.19	1.19	5
298 000	40	53.55	37.63	0.99	0.99	4

Table 13. Phosphorus output of critical erosion cells in the Punished Woman's Lake watershed.

			Nutrient Analysis PHOSPHORUS Sediment		Water Soluble		
Cell Num	Div	Drainage Area (acres)	Within Cell (lbs/a)	Cell Outlet (lbs/a)	Within Cell (lbs/a)	Cell Outlet (lbs/a)	Conc (ppm)
2	000	40	5.08	3.07	0.05	0.05	0
3	000	40	5.08	3.46	0.15	0.15	1
12	000	80	5.62	1.93	0.12	0.15	1
17	000	40	7.05	4.68	0.07	0.07	0
23	000	40	7.36	4.94	0.18	0.18	1
35	000	80	7.36	2.44	0.18	0.10	0
47	000	40	7.36	4.94	0.18	0.18	1
70	000	120	5.66	2.18	0.18	0.27	1
81	000	40	7.36	4.94	0.18	0.18	1
86	000	160	5.66	2.09	0.35	0.29	1
93	000	40	13.11	8.72	0.12	0.12	0
95	000	160	8.44	3.49	0.31	0.15	1
100	000	40	7.05	4.68	0.12	0.12	0
101	000	40	7.05	4.68	0.12	0.12	0
102	000	40	7.36	4.94	0.18	0.18	1
109	000	80	5.66	2.37	0.35	0.35	1
111	000	40	5.66	3.80	0.35	0.35	1
127	000	200	9.64	3.41	0.11	0.14	1
128	000	40	9.64	7.12	0.11	0.11	0
136	000	80	9.64	5.62	0.14	0.14	0
137	000	40	9.64	7.17	0.14	0.14	0
139	000	80	5.16	1.87	0.29	0.15	1
148	000	40	6.31	4.14	0.27	0.27	1
156	000	40	23.33	17.97	0.16	0.16	1
178	000	80	7.75	3.18	0.16	0.13	1
195	000	40	5.17	3.36	0.27	0.27	1
207	000	40	5.17	3.45	0.27	0.27	1
239	000	40	6.30	4.23	0.18	0.18	1
249	000	40	11.90	8.14	0.18	0.18	1
275	000	80	6.77	2.65	0.18	0.18	1
287	000	40	11.90	8.14	0.22	0.22	1
298	000	40	26.77	18.82	0.18	0.18	1

Table 14. Soil loss and sediment generated in watershed cells surrounding Punished Woman's Lake.

Condensed Soil Loss

		RUNOFF					SEDIMENT			
		Drainage		Generated	Peak	Cell	Generated			
Cell Num	Div	Area (acres)	Volume (in.)	Above (%)	Rate (cfs)	Erosion (t/a)	Above (tons)	Within (tons)	Yield (tons)	Dep (%)
199	000	800	0.93	96.2	541	0.64	276.79	25.72	260.03	14
200	000	80	0.93	59.0	107	0.64	4.24	25.72	17.03	43
201	000	120	0.93	74.2	133	0.64	17.36	25.72	27.50	36
202	000	80	0.44	73.2	84	0.22	2.67	8.88	5.78	50
203	000	200	1.21	79.2	215	0.22	32.85	8.88	29.80	29
204	000	80	1.21	46.1	123	0.22	11.27	8.88	11.75	42
205	000	40	1.21	0.0	99	0.22	0.00	8.88	5.73	35
206	000	6840	1.21	99.4	1847	0.17	2015.58	6.99	1889.45	7
212	000	840	1.84	93.1	483	0.05	260.03	1.99	222.39	15
213	000	120	1.84	55.3	120	0.05	17.03	1.91	11.14	41
217	000	40	0.73	0.0	73	0.69	0.00	27.74	17.30	38
218	000	40	0.73	0.0	73	0.69	0.00	27.74	17.30	38
220	000	6880	1.84	99.1	1425	0.05	1889.45	1.91	1781.55	6
226	000	360	1.21	89.8	289	0.16	53.42	6.43	47.63	20
227	000	3080	2.08	97.9	1206	0.05	1136.96	1.91	1063.58	7
240	000	80	1.34	43.7	111	0.16	136.68	6.43	80.13	44
241	000	1720	0.98	98.2	904	2.57	862.38	102.89	855.79	11
242	000	480	0.98	93.5	350	2.57	115.91	102.89	156.34	29
243	000	40	0.93	0.0	73	0.64	0.00	25.72	15.48	40
255	000	40	1.21	0.0	92	0.16	0.00	6.43	4.19	35
256	000	40	1.34	0.0	101	0.16	0.00	6.43	4.59	29
257	000	400	1.21	90.8	337	0.16	119.99	6.43	100.42	21
258	000	360	1.34	88.8	366	0.22	134.73	8.88	119.99	16
260	000	680	2.26	89.0	421	0.07	123.56	2.69	116.56	8
261	000	40	2.26	0.0	170	0.07	0.00	2.69	2.43	10

Table 15. Nutrient output of watershed cells surrounding Punished Woman's Lake.

Cell Num	Div	Drainage Area (acres)	Nutrient Analysis NITROGEN Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm
199	000	800	2.22	1.29	0.18	0.53	2
200	000	80	2.22	0.92	0.18	0.22	1
201	000	120	2.22	0.97	0.18	0.24	1
202	000	80	0.95	0.39	0.09	0.16	1
203	000	200	0.95	0.69	0.24	0.41	2
204	000	80	0.95	0.68	0.24	0.45	2
205	000	40	0.95	0.67	0.24	0.24	1
206	000	6840	0.78	1.10	0.24	0.71	3
212	000	840	0.29	1.09	0.37	0.52	2
213	000	120	0.28	0.47	0.37	0.27	1
217	000	40	2.36	1.62	0.14	0.14	1
218	000	40	2.36	1.62	0.14	0.14	1
220	000	6880	0.28	1.05	0.37	0.70	3
226	000	360	0.73	0.63	0.24	0.26	1
227	000	3080	0.28	1.35	0.43	0.48	2
240	000	80	0.73	3.17	0.27	0.63	2
241	000	1720	6.74	1.81	1.25	0.52	2
242	000	480	6.74	1.29	1.25	0.33	1
243	000	40	2.22	1.48	0.18	0.18	1
255	000	40	0.73	0.52	0.24	0.24	1
256	000	40	0.73	0.52	0.24	0.24	1
257	000	400	0.73	1.04	0.24	0.26	1
258	000	360	0.81	1.11	0.26	0.26	1
260	000	680	0.37	0.77	0.47	0.24	1
261	000	40	0.37	0.34	0.47	0.47	1

Table 15. Continued.

Cell Num	Div	Drainage Area (acres)	Nutrient Analysis PHOSPHORUS Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
199	000	800	1.11	0.64	0.01	0.07	0
200	000	80	1.11	0.46	0.01	0.01	0
201	000	120	1.11	0.49	0.01	0.01	0
202	000	80	0.47	0.19	0.01	0.01	0
203	000	200	0.47	0.34	0.01	0.05	0
204	000	80	0.47	0.34	0.01	0.06	0
205	000	40	0.47	0.33	0.01	0.01	0
206	000	6840	0.39	0.55	0.01	0.11	0
212	000	840	0.14	0.55	0.02	0.07	0
213	000	120	0.14	0.24	0.02	0.02	0
217	000	40	1.18	0.81	0.01	0.01	0
218	000	40	1.18	0.81	0.01	0.01	0
220	000	6880	0.14	0.52	0.02	0.11	0
226	000	360	0.37	0.31	0.01	0.01	0
227	000	3080	0.14	0.68	0.02	0.06	0
240	000	80	0.37	1.58	0.02	0.10	0
241	000	1720	3.37	0.91	0.24	0.07	0
242	000	480	3.37	0.64	0.24	0.03	0
243	000	40	1.11	0.74	0.01	0.01	0
255	000	40	0.37	0.26	0.01	0.01	0
256	000	40	0.37	0.26	0.01	0.01	0
257	000	400	0.37	0.52	0.01	0.01	0
258	000	360	0.40	0.56	0.02	0.01	0
260	000	680	0.18	0.39	0.03	0.01	0
261	000	40	0.18	0.17	0.03	0.03	0

Table 16. Simulation of nutrients in urban runoff from South Shore cells #260 and #261.

Nutrient Analysis
N I T R O G E N

Cell Num	Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220	000	6880	0.28	1.07	0.37	0.70	3
227	000	3080	0.28	1.35	0.43	0.48	2
242	000	480	6.74	1.29	1.25	0.41	1
260	000	680	0.37	0.77	9.01	0.74	3
261	000	40	0.37	0.34	4.74	4.74	9

Nutrient Analysis
P H O S P H O R U S

Cell Num	Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220	000	6880	0.14	0.54	0.02	0.11	0
227	000	3080	0.14	0.68	0.02	0.06	0
242	000	480	3.37	0.64	0.24	0.05	0
260	000	680	0.18	0.39	1.97	0.13	0
261	000	40	0.18	0.17	1.00	1.00	2

Table 17. Nutrient mass and concentration at five Punished Woman's Lake tributary inlets with 4 of 12 upstream feedlots deleted.

Nutrient Analysis
N I T R O G E N

Cell Num Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220 000	6880	0.28	1.06	0.37	0.74	3
227 000	3080	0.28	1.35	0.43	0.50	2
242 000	480	6.74	1.29	1.25	0.41	1
260 000	680	0.37	0.77	0.47	0.24	1
261 000	40	0.37	0.34	0.47	0.47	1

Nutrient Analysis
P H O S P H O R U S

Cell Num Div	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
220 000	6880	0.14	0.53	0.02	0.12	0
227 000	3080	0.14	0.68	0.02	0.07	0
242 000	480	3.37	0.64	0.24	0.05	0
260 000	680	0.18	0.39	0.03	0.01	0
261 000	40	0.18	0.17	0.03	0.03	0

OFFICE OF WATER RESOURCES MANAGEMENT

TIM BJORK - OFFICE ADMINISTRATOR

WAYNE HOUTCOOPER - SENIOR SCIENTIST **DUANE MURPHEY - SENIOR SCIENTIST**

JIM ANDERSON - ENGINEER
RICH HANSON - PROGRAM SCIENTIST
PHIL LIDEL - ENGINEER
KEN MADISON - SCIENTIST
ANDREW REPSYS - SCIENTIST
BILL STEWART - SCIENTIST
GENE STUEVEN - SCIENTIST
PAUL SZEWCZYKOWSKI - SCIENTIST