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**REPORT OF INVESTIGATIONS WITH RECOMMENDATIONS,
BIOLOGICAL FOULING OF THE TOE AND WEEP DRAINS,
PABLO DAM**

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**Report of Investigations with Recommendations,
Biological Fouling of the Pressure Relief Drainage System,
Pablo Canyon Dam, Montana**

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I. Overview

The Pablo Dam located in the Montana Flathead Irrigation District (between Missoula and Kalispell, MT) is a earthen dam approximately 3000 feet long and was originally constructed in the late nineteen twenties. It has undergone two major phases of reinforcement and drain enhancement, once during the thirties and later in the late eighties. The toe drain system drainage flows into a wetland below the dam. Over time there has been a 30-50% water flow reduction in the toe drains and some minor sloughing of the dam side slopes has occurred. Blockages in the drainage network by biofouling (complicating sediment and mineral clogging) are suspected of causing of this flow reduction.

As discussed in "Draft Drainage for Dams and Associated Structures," properly functioning drainage structures are necessary for dam safety and proper function. A fact worthy to note was that out of 4,000 dams in the dam database, 46 dam failures were reported, and of those 21 had documentation available. Only one out of those 21 failed dams had a drain system in place, which leads to the conclusion that drains are vital to dam safety (Reclamation). As is true of other drainage or pumping structures, drainage systems of dams are rendered less effective by a range of natural mechanisms, including geochemical incrustation and biological fouling. Effective, long lasting cleaning of these systems remains an elusive goal. Consequently, it is well recognized that preventive maintenance programs (PM) that include a protocol for monitoring clogging mechanisms is beneficial to dam safety.

The Pablo Dam drainage system consists of two different drain systems, the toe drains and the weep drains. The primary drainage system is the toe drain, which facilitates the drainage at the toe or base of the dam. These drains run into manholes (MH-6, MH-7, MH-10, MH-11, MH-12, MH-13, MH-14, MH-15, & MH-16) that also collect drainage from the lateral outfall drains. The manhole drainage then drains into a weir that seeps into the wetland below the dam. Secondly, there are a series of seep drains that drain into the outlet works where the gate controls the irrigation outflow.

Suspected biofouling materials in samples received from Pablo Reservoir in early 2001 were tentatively identified as iron bacteria. Based on this preliminary information pointing to biological fouling of the pressure relief drainage system, a study to sample and analyze the biofouling and water quality of the accessible parts of the drain well and toe drain system was organized (Phase I of planned FY 2001 work). The Reclamation Geotechnical Engineering Group conducted several studies of the Pablo drain system, which included video monitoring of the undisturbed drains. Also in the Phase I effort, the USBR Integrated Pest Management Team (IPMT) provided oversight for the drain system microbial community evaluation and species identification. The IPMT conducted the evaluation in cooperation with Stuart Smith, Ground Water Consultant of Smith-Comeskey Ground Water Science, and Dr. Eleanore Robbins, USGS Microbiologist.

This report is a summation of the data collection efforts of the Phase I work. The recommendations are of a general nature, and while the authors have some specific treatment recommendation to offer, the feasibility of those options remain in question until further site-specific information is obtained.

II. Field work and Data collection

During mid-April, the Geotechnical Engineering Group conducted a video survey of the Pablo Dam toe drain system below the reservoir, which provides visual proof of the extent of the biofouling problem (figure). Then on April 23, 2001, Denise Hosler and Stuart Smith with the assistance of Ronan, Mt. Area Office personnel conducted a site survey and data collection. Water samples were analyzed onsite for pH, temperature, conductivity, and redox potential (Eh). Additionally, water and biofilm samples were collected for chemical analysis and biofoul culture and analysis in the laboratory.

Biofouling analysis

Methods chosen were intended to (1) rapidly define the active microbial ecology present and (2) also to provide a detailed description of biofouling components to aid in selecting cleaning methods. Cultural methods and light microscopy were chosen to permit a relatively rapid and useful analysis of the presence or absence (P/A) of metabolic/respiratory and morphologically distinct types of micro flora present.

Cultural Biological Activity Reaction Test (BART) methods: BART methods (heterotrophic culturing) and their application are explained in the report appendix. Briefly, BART tubes contain a dehydrated selective or differential culture medium selected for the microbial group of interest (iron-related bacteria, etc.), and a plastic ball in a 15-mL tube. Adding sample water hydrates the medium, and a redox gradient forms between the ball and the medium in the bottom. Interpretation is based on observation of the medium appearance and time it takes for a reaction to occur.

Light microscopy: Light microscopy was employed to describe the types of biofilms present in samples, and provide presumptive identification of biofouling micro flora and metal oxide particles by morphology. Water samples containing solids were observed as wet mounts.

Scanning electron microscopy (SEM) and elemental dispersive scatter (EDS) analysis: As analysis of the composition of materials by light microscopy is inexact, an attempt was made to define (qualitatively) the composition of biofouling and other solids deposited in toe drains, drain wells, and manhole sumps. SEM was employed to confirm light microscopy identifications and to provide more detailed photographs for analysis. Associated EDS (in conjunction with SEM-revealed deposit structure) provided insight into deposition mechanisms.

Additional insight into the composition of solids accumulated in biofilms and on surfaces was provided by ICP metal analysis.

III. Summary of Data Results

Observations of manholes and toe drains

Several of the manholes and associated toe drains and drain wells exhibited visible evidence of biofouling. Toe drains (in particular those entering manholes (MH) 10, 11, 12, 13 and 14) had light tan to black biofouling at or below the water level in the drain. (**See photos**) MH 14's sump was heavily populated by soft, filamentous biofouling lining the walls, submerged surfaces, and as globules in the water. Additionally, similar growth was visible in the MH 14 discharge weir, growing on the weir plate. Weep drains also revealed evidence of microbial growth, with the occurrence of dark tan, black, and white biofilm. Aside from the visual observation of biofilm, the chemical data indicates that several microbial processes are effecting the chemical reactions that contribute to the sediments in the drain system.

Field vs. lab physical parameters:

The general water chemistry analyses revealed suitable conditions for long-term microbial growth, that is, a neutral pH, with abundant dissolved oxygen, total organic carbon, nitrogen, and phosphorus available for metabolic processes. Conductivity and pH measurements taken in the field and again in the lab differ, conductivity going up in the lab and pH dropping (graph), both instrumentation differences and microbial activity within the samples may account for these differences.

The redox measurement in the field reported as bulk mVs, was adjusted to Eh (in reference to H+) and plotted vs. pH. The Eh is generally in the range of Fe(OH)₃ deposition (Hem, 1985). The Fe³⁺ (total Fe - Fe²⁺) was 66-99 % of total Fe in samples evaluated, indicating ample Fe³⁺ availability for deposition. Additionally, the presence of Mn-containing deposits suggests that microbial deposition of MnIV oxides is occurring, as Eh-pH values are outside the range of autooxidation of Mn oxide deposition and Mn²⁺ was the predominant Mn form in water samples except in MH-7 and MH-16.

There were other indicators of the influence of microbial activity on the drain system and they included:

- High concentrations of Fe and Mn generally occurred in samples from locations with low mV readings in water (see graph). This is possibly due to Fe and Mn reduction, as there does not seem to be any lack of Fe and Mn oxide deposition.
- All samples except MH 15 basin had Mn values greater than Fe values, indicating active Mn reduction is occurring.
- High Fe and Mn also appear to match up to higher NH₃-N levels.
- NH₃-N parallels with lower mV values and reactivity rate (see chart, with MH 10, MH 11, and MH 14 NH₃-N elevated).
- MH 14 water (all three clear water samples), which exhibited extensive biofouling had among the lowest in organic P, evidence of microbial uptake of P.
- Among solids, ICP/ES indicated that Mn was greater than Fe in seep biofouling solids samples, the reverse of manhole solids. This suggests variety in microbial deposition.

BART analysis:

BART cultures demonstrated positive results for Iron Related Bacteria (IRB), Slime Forming Bacteria (SLYM), and to a lesser extent Sulfate Reducing Bacteria (SRB). The number of days until the appearance of bacterial growth listed in Table 1. Details of the BART cultures may be found in the Appendix field notes. Based upon the days until appearance or days of delay before cultures appear, the populations or colony forming units per milliliter may be estimated using Table 2.

Table 1. BART Reactions

Sample Location	BART Type and Days to Reaction				
	IRB 1*	IRB 2	Slym	SRB 1	SRB 2
MH 6	3**	4	4	4	0
MH 7	3	4	4	4	0
MH 10	3	4	4	0	0
MH 11	3	4	4	3	0
MH 12	3	4	6	4	0
MH 13	4	5	2	0	0
MH 14	6	8	8	5	0
MH 15	4	5	3	4	6
MH 16	5	7	3	2	5
Seep 1	1	3	2	0	0
Seep 2	2	3	2	1	1
Seep 3	1	4	2	1	0
Seep 4	1	1	2	4	0

* IRB = iron related bacteria, Slym = slime-forming bacteria, SRB = sulfate-reducing bacteria. IRB 1 is the first IRB reaction and IRB 2 the second observed, same with SRB. SRB 1 was usually BT (blackening at top).

** These are days until a reaction occurred (days of delay or time lag) after inoculation. A '0' indicates no reaction.

The IRB reaction types tended to be those of anaerobic or facultatively anaerobic heterotrophs. Heterotrophic bacteria are present at $10^{3.5-4.0}$ CFU/ml (less in some) in water samples tested (IRB-BART and SLYM-BART), and sulfate-reducing bacteria (SRB) at $10^{4-4.6}$ (when present). Days of delay are converted to cells per milliliter values using the following relationship table:

Table 2. Relationship between DD and log CFU/ml for BART used (DBI, 1999)

Time lag (DD)	IRB	SRB	SLYM
0.5	6.6	6.6	6.8
1.0	6.0	6.0	6.6
1.5	5.8	5.8	5.8
2.0	5.0	5.0	5.6
3.0	4.0	4.6	4.6
4.0	3.6	4.0	3.0
5.0	3.0	3.6	2.6
6.0	2.0	3.0	2.0
7.0	2.0	2.0	1.0
8.0	2.0	2.0	1.0

DD are expressed as days until a reaction occurs. The CFU/ml conversions are expressed as log CFU/ml. Thus, for a culture in an IRB-BART tube (results vary among types), DD 2 = 10⁵ CFU.

Light Microscopy

Light microscopy observational results are as follows for samples with identifiable structures:

MH 10	<i>Thiothrix</i> (fine, thin nonmotile light-colored filaments with minor inclusions)
MH 12	<i>Thiothrix</i> , <i>Leptothrix ochracea</i> , <i>Sphaerotilus</i> , and occasional ciliates
MH 13	<i>Thiothrix</i> , probably <i>Leptothrix</i> or <i>Sphaerotilus</i>
MH 14	<i>Thiothrix</i> , Fe-encrusted <i>Leptothrix</i> or <i>Sphaerotilus</i> , <i>Crenothrix polyspora</i> (wall), cyanobacteria, abundant ciliates
S-2 weep	<i>Leptothrix ochracea</i> , Mn oxides (buserite), <i>Thiothrix</i> , abundant ciliates
S-2 weep wall	Flocular Mn oxide particles
S-3	similar to S-2

Eleanora Robbins, Ph.D., United States Geological Survey, May 25, 2001

Filamentous bacteria in the light tan toe drain biofilms were colorless (lacking Mn or Fe staining) and had abundant, irregularly separated small cells in sheaths lacking partitions. These were identified as *Thiothrix* on this basis. *Leptothrix* (iron-stained and incrusting) were identified in MH 14. *Crenothrix polyspora*, typically not iron-encrusting, and having large cylindrical cells, was also present in MH 14.

SEM and EDS

Features of note from selected SEMs (see enclosed images):

- 1-1 and 1-1s (and others): *Thiothrix*-type filaments
- 1-2: Typical larger magnification of filaments with inclusion
- 1-3 , 3-7 *Gallionella* stalk also identified (not identified by light microscopy).

- Light microscopy is a useful adjunct. With SEM having reinforced light microscopy results, site personnel may be trained to identify the various bacteria and mineral structures that are related to the depositions found in the drain system.
- The ICP/ES and EDS methods of characterizing solids metals/material content complemented one another and together, using data reported, permitted a reasonable conclusion to be drawn about materials present. ICP/ES provided quantitative results so that a mineral identification for solids can be made for bulk samples. Although EDS does not provide quantitative results, it permits "spot" identification of individual structures (individual crystals, etc.) so that the variety of materials present can be appreciated. This type of analysis can be done infrequently in the reconnaissance phase of problem identification in structures.

(5) While it is not within the scope of this investigation to evaluate the hydraulic performance of the Pablo Dam drainage system and its geotechnical engineering (this is being investigated separately by the Civil Engineering section of the TSC), experience shows that clogging of water systems and drains can and do occur under the biogeochemical conditions described. Clogging mechanisms that are expected to be highly active, based on the above-mentioned results are outlined as follows:

- Microbial Fe and Mn oxide deposition. The volume of deposition is typically increased where Mn and Fe reduction occurs in anaerobic zones, and the Fe^{2+} and Mn^{2+} are subsequently oxidized to their poorly soluble valence states. Mn-oxide formation was observed.
- Where denitrification occurs (ammonia formation), Fe^{2+} and Mn^{2+} may serve as electron acceptors and be oxidized.
- Clogging of drains and weeps by filamentous biofilms, both metal (*Leptothrix* and *Gallionella*) and sulfur-depositing (*Thiothrix*). White sulfur deposition was observed in seeps and *Thiothrix* in toe drain outlets.
- Mineral deposition, including possible microbial aluminum silicate deposition, adds to intergranular clogging around drain and seep openings.

Recommendations

- (1) Further investigations of drain water quality and system performance are recommended over time to provide a more complete picture than is possible from one limited investigation. This can be conducted site by the following activities:
- Analyzing for physical properties (pH, Eh, conductivity, temperature); and
 - Conducting BART bioanalysis (SRB, IRB, SLYM, and adding DN), supplemented by culturing for Mn-precipitating and S-oxidizing micro flora.
- Selected metals and ionic properties (including alkalinity) may be analyzed periodically either by formal laboratory analysis which may be supplemented by field-laboratory analysis.

- (2) It would be useful to establish a model system, designed to mimic the natural system, in order to study how the microbial ecology of the drainage system operates, and to explore control and cleaning systems. An important aspect of decisions about cleaning protocols is potential impact on downstream Tribally managed wetlands. Biototoxicity is best studied in a model system in the early phases. We recommend that the study team design and implement such a study.
- (3) We recommend close collaboration with the ongoing geotechnical monitoring to assist them in (a) explaining any changes in pressure within the structure and (b) making modifications that would reduce the impact of biological activity on the drainage system's performance. One such recommendation to increase the number of drainage wells to alter the growth environment for the microbes while reducing the impact of clogging at any one point.
- (4) Upon review of the draft *Drainage for Dams and Associated Structures*, we did not note mention of the Army Corps of Engineers' extensive study of methods to clean drainage wells and toe drains of biological fouling. We recommend that the study team assist the manual's editorial team in integrating this parallel body of work.
- (5) Drawing from case history experience and the model study parallel to it, we recommend establishing some pilot drain and weep cleaning programs, starting with MH 14 and a second impacted system, such as MH 13 or MH 10 that provide geochemical contrast (low vs. higher Eh, etc.). Using preliminary model results, a mild cleaning program demonstrated to be nontoxic to aquatic life downstream of the weirs and with promising physical cleaning tools can be tested and level of effectiveness determined.

References

- Bureau of Reclamation, 2001. Draft Drainage for Dams and Associated Structures, Civil Engineering and Geotechnical Services, Technical Service Center, U.S. Department of Interior, Denver, CO.
- DBI. 1999. Biological Activity Test (BART™) User Manual. Droycon Bioconcepts Inc., Regina, Saskatchewan. Found up-to-date at URL <http://www.dbi.sk.ca>.
- Hem, J.D. 1985. *Study and Interpretation of the Chemical Characteristics of Natural Water*, U.S. Geological Survey Water-Supply Paper 2254, Third Edition, U.S. Geological Survey, Reston, VA.
- Robbins, Eleanor I., Personnel communications April 2001 and light microscopy session held at the Denver Federal Center, May 25, 2001.

Appendices