

# RECLAMATION

*Managing Water in the West*

## Water Operation and Maintenance Bulletin

No. 208



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Labor-Saving Debris and Fish Screens

Interim Report – Evaluation and Remaining Service Life of  
Protective Coatings by Electrochemical Impedance Spectroscopy (EIS)



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*Cover photograph – Rocky Mountain Arsenal screen.*

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## Labor-Saving Debris and Fish Screens

by Tony L. Wahl<sup>1</sup>, Robert K. Weir<sup>2</sup>, John K. Cerise<sup>3</sup>,  
Brian Sauer<sup>4</sup>, and Jack Wergin<sup>5</sup>

Problems caused by debris in irrigation water can be expensive and troublesome issues for irrigators and water districts, especially as many water users convert from traditional set-tube flood irrigation to more modern application methods such as gated pipe and sprinklers. Debris can plug gated pipe orifices and sprinkler nozzles or clog valves and flow metering equipment. These problems usually lead districts to attempt to screen debris from irrigation water before it can cause such problems, but even on projects where debris screens have been installed, the maintenance and cleaning of screens themselves often becomes a full-time job.

Many different trash screen and trashrack designs have been developed through the years to address the need for low-maintenance screening. Traveling screen systems, vibratory screens (e.g., the Yak screen), and turbulent fountains have all had some success, but the goal of truly maintenance-free screening has not yet been reached. Now, a new application of an old technology first developed in the mining industry is bringing us closer to this goal. Although not absolutely maintenance free at every site, Coanda-effect screens are substantially self-cleaning with no moving parts, and they require less maintenance than most other screening systems. These screens are able to remove debris as small as a fraction of a millimeter when necessary. There have been many applications of these screens throughout the world and in the United States during the past 25 years, mostly on small hydropower installations where the screens remove both debris and fish. In the past few years, several small screens have been installed in irrigation applications in the Western United States. Several of those installations are described in this article.

For those seeking additional information, brief case histories of many small hydropower screen installations are given in the appendix of a new design guide for Coanda-effect screens (Wahl 2003). Additional technical details and a mathematical model for evaluating the hydraulic performance of these screens are given in Wahl (2001). Finally, a computer program available via the Internet from the Bureau of Reclamation (Reclamation) can be used to analyze screen

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hydraulic performance. This program was used to develop the new design guide. The program and other references are available at <[http://www.usbr.gov/pmts/hydraulics\\_lab/twahl/coanda/](http://www.usbr.gov/pmts/hydraulics_lab/twahl/coanda/)>.

## How Coanda-Effect Screens Work

The primary features of a Coanda-effect screen are illustrated in figure 1. The screen is installed on the downstream face of an overflow weir. Flow passes over an acceleration plate and then across a wedge-wire screen panel. The wires in the panel are horizontal, perpendicular to the flow across the screen. The screen panel may be either flat or concave. Flow passing through the screen (screened flow) is collected in a conveyance channel beneath the screen, while overflow, fish, and debris pass off the downstream end of the screen. Flow velocities across the screen are typically 6.5 to 10 feet per second, increasing toward the toe of the screen. In past hydropower applications, commercially available designs typically had the screen inclined  $60^\circ$  from horizontal at the upstream edge, with a total head drop across the structure of about 4 to 5 feet. However, many of the applications described in this paper use much flatter screen angles and operate with much smaller head loss.

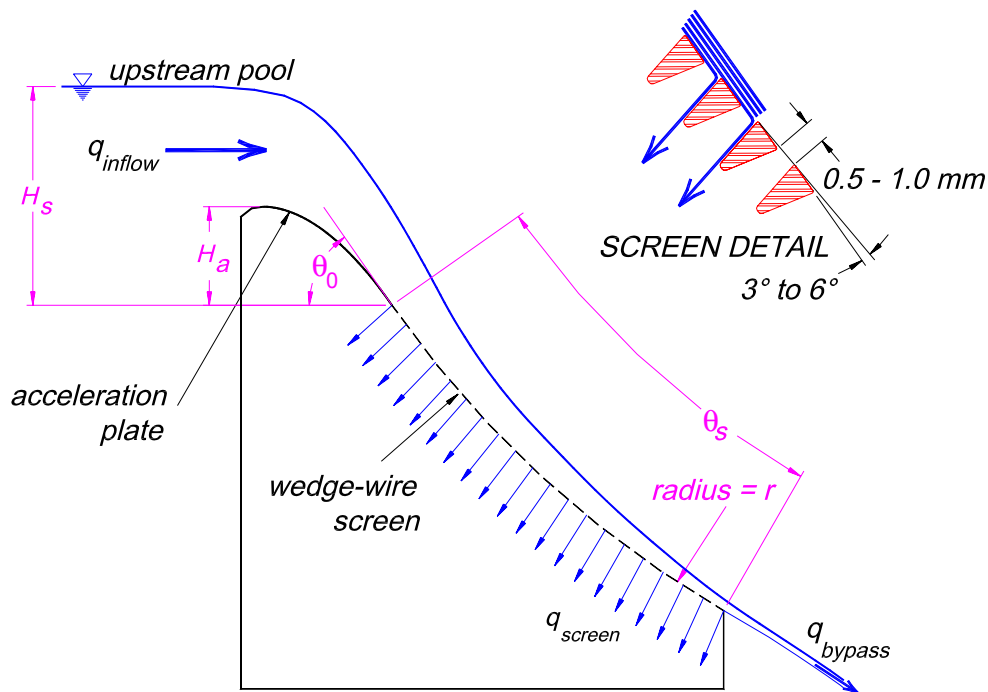


Figure 1.—Features, typical arrangement, and design parameters for Coanda-effect screens.

Coanda-effect screens use a unique tilted-wire screen panel. The individual wires are tilted a few degrees downstream (see detail, figure 1) to produce shearing offsets into the flow above the screen. The typical tilt angle is  $5^\circ$ , but angles of  $3^\circ$  to  $6^\circ$  are available from most screen manufacturers. Slot widths between the wires are typically 1 millimeter (mm) (0.04 inch) or less. The shearing action is enhanced by flows that remain attached to the top surface of each wire and are thus directed into the offset created at the next downstream wire. This attachment of the flow to the top surface of each wire is an example of the Coanda effect, the tendency of a fluid jet to remain attached to a solid flow boundary. A detailed discussion of the Coanda effect and its application to tilted-wire screens is provided by Wahl (1995).

The benefits of improved screening are numerous. With less debris, water can be applied faster and with better uniformity. On one gated pipe system, it was reported that fields that formerly took 5 days to poorly irrigate could now be irrigated in 2 days with more uniform flow for each row. Irrigation ditches are also a common source of weed seeds that move into the fields with the water. A commonly used wire spacing of 0.5 mm (0.019 inch) will screen out about 90 percent of the debris larger than 0.25 mm (.009 inch). This will effectively remove most weed seeds and therefore reduce labor and costs incurred in the control of noxious weeds.

## **Boise Project, Idaho**

The screen shown in figure 2 was installed on the Boise Project to provide removal of fine debris at a drop structure and flow metering box serving both flood and sprinkler-irrigated farms. The Coanda-effect screen was installed during the spring of 2003. The new stainless steel screen is 3 feet long and 8 feet wide, with 0.5 mm slots. This screen is cleaned a couple of times per week. The Boise Project underwent two minor modifications after the screen was installed. First, small flow deflectors were added near the top edge of the accelerator plate because debris was collecting where the screen met the sidewall of the concrete box. The deflectors successfully keep the edges of the screen clean. Second, a staff gate was added upstream from the weir to allow making a rough estimate of the flow being delivered to the screen. This measurement only approximates the flow actually delivered to farmers on this lateral since a small amount of overflow passes off of the screen into a bypass pipe that leads back to the canal. Downstream from the screen, piped farm deliveries are measured with paddle-wheel-type insertion flow meters, and since the screen was installed, there has been little problem with the meters. This screen was installed as a demonstration project through a 50 percent cost share between the irrigation district and Reclamation's Science and Technology Program.

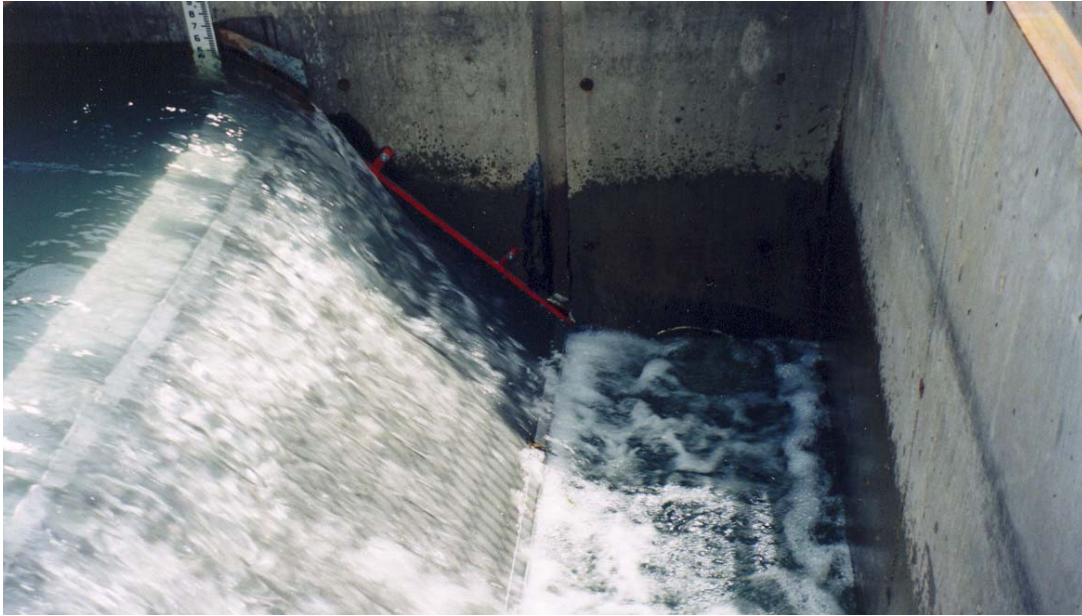


Figure 2.—Coanda-effect screen installed on the Boise Project, Idaho. Clean water drops through the screen section into a conveyance channel beneath the screen. A staff gage and sheet-metal flow deflector are visible at the upstream corner of the screen.

## Pioneer Irrigation District, Colorado-Nebraska

As part of recent modernization efforts, the Pioneer Irrigation District has been converting from flood to sprinkler irrigation systems. To facilitate this conversion, the district has added several Coanda-effect screen devices. Those shown in figures 3 through 5 are incorporated into low-pressure piped delivery systems. In each case, the pipe is interrupted by a well that contains a Coanda-effect screen. Flow enters the well and builds up to flow over a weir and across the screen. The screened flow is collected beneath the screen and exits the well into a discharge pipe. The debris passes over the screen and is discharged out the side of the structure. These devices consume a few feet of head, which has not been a problem for this district, but might be an issue on other projects.

## Lake John

For many years the Colorado Division of Wildlife has tried to limit the entry of carp and sucker eggs and larvae into Lake John in an effort to preserve and maintain a sport fishery there. In the 1990s they constructed a sand filter device (figure 6) like those often used in water treatment applications, but maintenance of the filter was a serious problem. Backwashing and reconditioning of the filter was required on a frequent basis. Cleaning involved lowering a burning cherry bomb held in the jaws of a wrench into the structure, where its detonation disturbed the accumulated fine sediments.



Figure 3.—Coanda-effect screen structure built with corrugated metal pipe. Raw water enters from the right. Clean water is discharged through the center and left-hand pipes, while debris exits onto the ground through the slot in the left side of the structure.



Figure 4.—Coanda-effect screen structure feeding two irrigation pipelines. Raw water enters the back of the structure through the white, polyvinyl chloride pipe. Screened water exits to the right and left. Overflow and debris are discharged onto the ground at the front of the screen.





Figure 5.—Coanda-effect screen structure, similar to that shown in figure 4, operating at a relatively high flow rate. All flow still passes through the screen before reaching the toe.



Figure 6.—Sand filter at Lake John. This structure presented some exciting maintenance challenges.

In July 2001, the Division of Wildlife replaced the sand filter structure with four panels of tilted-wire Coanda screens on the irrigation ditch diversion to Lake John. Each panel measured 5 feet wide by 47 inches long. The wire slot opening

was 0.5 mm (0.019 inch), small enough to exclude the undesirable fish and larvae. The design discharge was approximately 30 cubic feet per second ( $\text{ft}^3/\text{s}$ ). To date, the screens have easily accepted the full design flow, but the outlet channel capacity beneath the screens has been somewhat less, preventing screen operations at the full design flow. Despite this problem, the screens themselves have worked well and have significantly reduced the maintenance problems associated with this site. Plans are currently underway to install similar screens on the supply to adjacent lakes.



Figure 7.—Coanda-effect screen structure at Lake John, constructed in 2001. This structure replaced that shown in figure 6.

## Rocky Mountain Arsenal Wildlife Refuge

The Rocky Mountain Arsenal is a former Department of Defense facility near Denver, Colorado, that is being converted into a wildlife refuge. A Coanda-effect screen was installed in the spring of 2000 for the U.S. Fish and Wildlife Service to exclude undesirable fish, fish eggs, and larvae from water being supplied from the Farmer's Highline Canal to several wetland ponds and lakes on the refuge. The screen replaced previous wire mesh screen panels that had required cleaning several times per day. The new screen has required cleaning only intermittently, when personnel visit the site for other reasons. The structure is 20 feet long with a design flow of  $20 \text{ ft}^3/\text{s}$ . The screen is capable of accepting much greater flows, but the receiving channel beneath the screen proves to be slightly undersized and

cannot quite accept the full 20 ft<sup>3</sup>/s. A small amount of flow bypasses the screen due to obstructions beneath the screen surface created by the support structure for the screen. The screen has performed well since its installation.



Figure 8.—Rocky Mountain Arsenal screen.

## **Small Hydro Installations**

Small hydropower sites have been a common application for Coanda-effect screens because of the need for low-maintenance screening in remote environments. Two notable installations with relatively long operating histories are Montgomery Creek (since 1985) and Forks of Butte (since 1991), both in northern California.

The Montgomery Creek site is about 40 miles northeast of Redding, California, just below the confluence of the two creeks. The design flow is about 120 ft<sup>3</sup>/s. The screen structure utilizes 24 Aqua Shear panels manufactured by Aquadyne, for a total crest width of about 36 meters (120 feet).

The project operators have been pleased with the performance of the structure, although they have modified the original design to make it more durable. These modifications included increasing the thickness of the accelerator plate and strengthening its attachment to the weir. Bolts used to attach the screens to the frame were modified and screens were welded to the accelerator plate. The width of the screen section is more than double the theoretically required width, but several factors reduce the theoretical capacity of the screens, including:

- One third of the screens are original and 15 to 16 years old. Wear has occurred on the screens, especially due to an increase in bed-load sediment passing over the screen following a large forest fire in the area several years ago.
- The water at this site is relatively warm and algae grow easily on the wedge wires. During the summer months the operator cleans the screens once per day.

- The accelerator plate curvature is too tight, causing the flow to arc over the top section of the screen during high flows.
- The transition between the accelerator plate and the screens is not smooth enough, causing water to skip over approximately 10 percent of the screen area.
- Some of the screens that were changed out due to wear have been replaced with planar panels rather than the original concave panels, which somewhat reduces their capacity.

The operators report that some sediment gets clogged between the wires, requiring an annual cleaning with a vibratory cleaner.



Figure 9.—Montgomery Creek intake.

The Forks of Butte diversion and powerhouse is located at Paradise, about 85 miles southeast of Redding, California. At this site, a dam diverts water into a side channel and the screen structure is parallel to the river. The structure is about 47 meters (150 feet) long, with a design capacity of about 210 ft<sup>3</sup>/s. Sediment has filled most of the pool upstream from the structure, causing an increase in approach velocity as the flow reaches the structure.

The operating experience here has been similar to that at Montgomery Creek. To strengthen the structure against vibration, the screen was welded completely to the support structure. Knee braces were also added beneath each panel. When screen panels were replaced due to wear, the wire thickness was increased from the original 1/16 inch to 3/32 inch. Unlike Montgomery Creek, there is no algae growth because the intake is in a deep canyon where little direct sunlight reaches the screens. The screens do not clog, and no cleaning maintenance is necessary.



Figure 10.—Forks of Butte intake.

## Small Agricultural Diversions in Western Colorado

Several small Coanda-effect screen structures have been installed in the past 2 to 3 years in western Colorado, primarily on projects converting from flood irrigation to sprinkler systems. The screens provide low-maintenance removal of fine debris that would potentially plug sprinkler nozzles. The screens are installed in modular turnout boxes that are installed into existing irrigation ditches (figures 11 and 12). Because head is limited, screens are often installed on slopes of about  $10^\circ$  to  $15^\circ$ . Typical sizes are about 2 to 3 feet wide and 3 feet long, with design diversion capacities less than  $10 \text{ ft}^3/\text{s}$ . Screens typically have a 0.5 mm slot width. Most of these screens have worked very well, and new installations continue to be made. The few problems have occurred at sites where there was very little head drop available, so tailwater submerged most of the screen and reduced the velocity across the screen surface, which allowed some clogging to occur.

## Modular Screen Structures for Diversions at Canal Checks

At canal check structures, a unique screen structure has been developed that is easily incorporated into an existing check. Figure 13 shows the structure, which contains a wedge-wire screen and an underlying stainless steel chute attached to a



Figure 11.—A small Coanda-effect screen provides water to a sprinkler irrigation system near Carbondale, Colorado.



Figure 12. — Modular Coanda-effect screen structure. Flow is toward the reader. Screened flow exits to the right through the flanged pipe connection.

polyvinyl chloride (PVC) pipe. The flow passes through the screen and down the chute into the PVC pipe. The deep vault beneath the screen shown in figure 12 has been eliminated. Note the flap at the bottom of the screen in figure 13. To stop the diversion, check boards are removed to eliminate flow over the screen and the flap is raised to prevent flow entering the screen from the downstream channel. Figures 14 and 15 show plan and elevation views of a typical installation.



Figure 13.—Coanda-effect screen structure in the shop, configured to discharge directly into a PVC pipe.

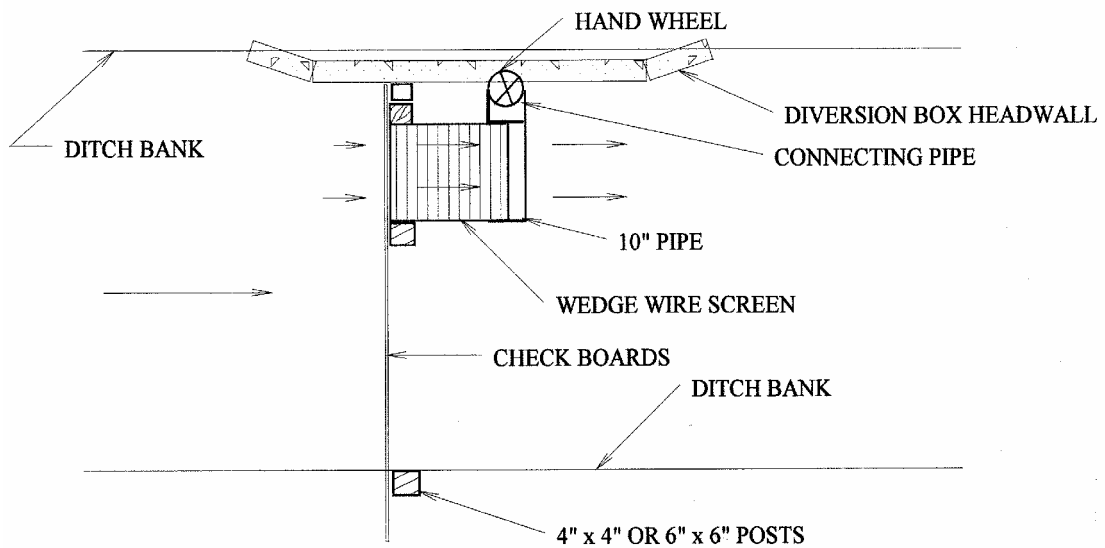


Figure 14.—Plan view of a Coanda-effect screen incorporated into a stoplog check.

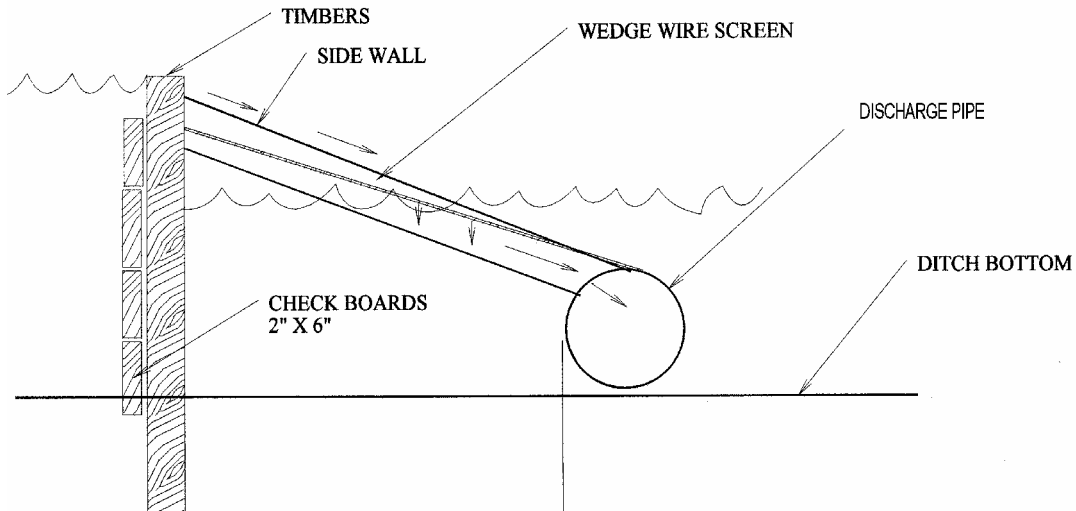


Figure 15.—Elevation view of Coanda-effect screen installation at a stoplog check.

## Conclusions

Coanda-effect screens can be adapted to solve a wide variety of water screening problems. If adequate sweeping flow is maintained across the screen face, minimal cleaning maintenance will be required. Screens are available from several manufacturers, and design assistance is available from the Technical Service Center of the Bureau of Reclamation.

## Web Resources

Coanda-Effect Screen Software – [http://www.usbr.gov/pmts/hydraulics\\_lab/twahl/coanda/](http://www.usbr.gov/pmts/hydraulics_lab/twahl/coanda/)

AquaScreen Enterprises – <http://www.aquascreen.jbmj.com/>

HydroScreen Co., LLC – <http://www.hydroscreen.com/>

Norris Screens – <http://www.norrisscreen.com/products/hydroelectric.htm>

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**Note:** Electronic copies of these references are available at:  
<[http://www.usbr.gov/pmts/hydraulics\\_lab/twahl/coanda/](http://www.usbr.gov/pmts/hydraulics_lab/twahl/coanda/)>

# Interim Report – Evaluation and Remaining Service Life of Protective Coatings by Electrochemical Impedance Spectroscopy (EIS)

by Tom N. Bortak, SSPC<sup>1</sup>

## Introduction

The Bureau of Reclamation (Reclamation) has painted (coated) numerous hydraulic structures to protect against corrosion. Protective coatings are the primary method to prevent corrosion and increase durability. However, all coatings have a finite service life and will deteriorate with time. The time period a coating will provide protection is a function of the selected material, service environment, surface preparation, and application quality. These factors will determine the coating's performance characteristics and service life. Typically, the remaining useful service life of a coating is estimated by conventional inspection methods.

## Conventional Inspection

Reclamation and the coating industry have historically relied on periodic inspections to determine a coating's effectiveness. Inspections consist of visual observation of defects and percent rusting, dry film thickness measurements, and destructive testing. The results are compiled and compared to previous inspections to determine any degradation of coatings.

The percentage of rusting is used to determine the maintenance plan for spot repairs, overcoating, or total removal and replacement. Determination of the percent rust is highly subjective and prone to miscalculation. Furthermore, the inspections do not quantify the effectiveness of the coating against corrosion or provide the remaining service life of the existing coating.

## New Technology Inspection

Electrochemical impedance spectroscopy (EIS) is an emerging technology to supplement conventional coatings inspection. It can quantitatively measure the

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coating's effectiveness against corrosion and extrapolate the remaining service life. EIS is a nondestructive test method. Laboratory and field results have been generally consistent with field experience and service history of industrial protective coatings. EIS is gaining acceptance in the protective coating industry. See Appendix A for a detailed description of EIS.

## **Limitations**

EIS is limited to organic coatings and conductive substrates. Organic coatings are common to most of Reclamation's guide specification coating category materials, and EIS would be an effective tool on about 90 percent of Reclamation's coated structures. EIS does not work on porous materials such as cement mortar lining because the EIS measures the lowest impedance resistance, which will be the test solution rather than the cement mortar. Coatings with metallic pigments such as red-lead, zinc-chromate, and zinc-rich primers cannot be effectively measured because the metallic rich primers have less impedance resistance than the organic intermediate coat/topcoat. However, the organic intermediate coat/topcoat can be effectively measured. Laboratory and field tests have been more successful on coatings with a thinner dry film thickness, about 30 mils and less. Techniques are being developed to measure thicker films.

## **Results**

EIS provides the following two results: (1) quantitative numerical value for the coating's effectiveness against corrosion and (2) an extrapolated remaining service life.

To measure the coating's effectiveness, a single measurement or an average of several measurements is taken at a single point in time. These measurements indicate the coating's barrier properties as a numerical value above or below which corrosion protection is afforded to the substrate (see figure 1 in the appendix). Single point in time EIS measurement cannot be used to extrapolate the coatings remaining service life.

A coating's remaining service life can be extrapolated with EIS measurements taken at interval time periods (i.e., every 5th to 8th year). This progressive accumulation of data allows the degenerative barrier properties of the coating to be plotted against time. For example, a coating is measured using EIS after initial application and every 5th year thereafter until the coating is 25 years old. The plot can be extrapolated to estimate the coating's remaining service life (see figure 2 in the appendix). Depending on the complexity of the coated structure, one or two technicians can evaluate a structure in less than 2 days.

## Conclusions

1. EIS is a useful tool to evaluate a coating's performance and remaining service life and can be used by managers to reserve funding and schedule future work on coatings.
2. Reclamation should pursue EIS technology by hiring a reliable contractor to test a handful of structures so that we can further define the reliability and usefulness of EIS.

## Appendix A

# Electrochemical Impedance Spectroscopy (EIS)

The following provides an abbreviated explanation of the electrochemical impedance spectroscopy (EIS) concept, equipment, procedures, corrosion protection, and remaining service life.

## Concept

Organic coatings and the corrosion process have inherent electrical resistance and capacitance characteristics. Both of these characteristics are incorporated in the EIS technique to evaluate the coating and corrosion process through AC impedance measurements. The coating's AC impedance magnitude (resistance) varies with signal frequency and fluctuates with resistors and capacitors in the test circuit. Capacitors cause a phase-shift between the input and output that can be readily measured. The resulting impedance measurement is an indicator of the coating's barrier properties (i.e., permeability to water, ions, gases, and other corrosive species). Impedance results are given in Log Z, ohms-centimeter squared at 0.1 hertz ( $\Omega\text{-cm}^2 @ 0.1 \text{ Hz}$ ).

## Equipment

EIS field technique employs the following equipment: (1) biodegradable conductive gel; (2) meshed wire platinum cell incorporating a reference cell; (3) cabling and clamp; (4) AC power source that can be a fixed outlet receptacle, generator, or battery; and (5) portable computer and potentiostat, either combined or separate units.

## Procedure

The following are EIS field procedures: (1) dewater the feature just before the EIS measurement to keep the coating hydrated; (2) connect wire to bare ferrous substrate by clamp or magnetic clamp; (3) select test areas, must be within 100 feet of ferrous clamp connection point; (4) apply conductive gel; (5) apply meshed wire platinum cell over conductive gel, (6) apply AC current; and (7) record results on portable computer.

## Corrosion Protection

Single EIS measurements can be used to determine the coating's protection to underlying ferrous substrate. Newly applied coatings typically exhibit a measurement between  $10^9$  and  $10^{11} \Omega\text{-cm}^2$ . Coating impedance measurements greater than  $10^6 \Omega\text{-cm}^2$  indicate the coating is providing corrosion protection. Newly applied coatings with an impedance less than  $10^6 \Omega\text{-cm}^2$  indicate poor surface preparation, application, defective material, or improper material selection. Figure 1 shows the degree of the coating's corrosion protection to the substrate related to the coating impedance value.

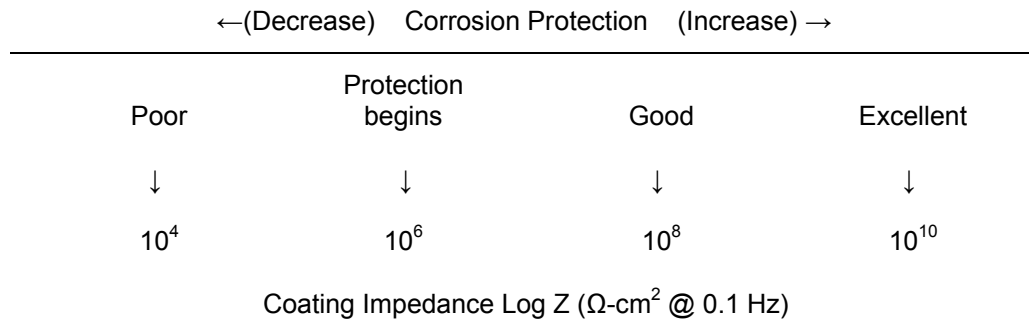


Figure 1.—Corrosion protection versus coating impedance Log Z measurement.

## Service Life

The useful remaining service life of a coating is extrapolated from periodic EIS measurements taken at intervening years. The result is a plot for coating impedance versus coating age. From the plot, the remaining useful service life can be extrapolated.

For example, in figure 2, if EIS measurements were taken initially after application and every 5th year thereafter until the 25th year, the remaining service would be estimated for a further 15 years. After the 40th year, the coatings impedance readings would be expected to be less  $10^6 \Omega\text{-cm}^2$ . This implies work on the coatings would be required at that time.

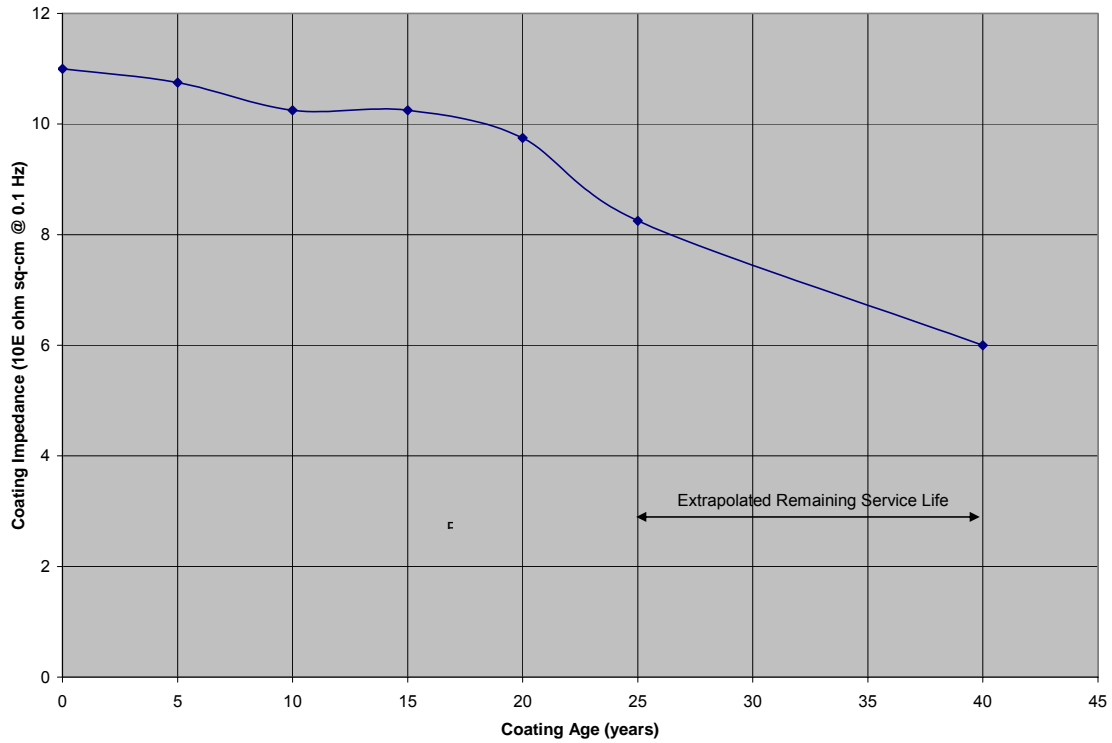


Figure 2.—Example of impedance versus age for a generic coating material with extrapolation after 25 years.

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## Mission

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

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