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Corrosion Mitigation

Irrigation Pump Intake Structures for Shallow Meandering River Applications

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Cover photograph *– Submersible intake with inlet parallel to streamflow.*

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Corrosion Mitigation

by Greg Myers[1]

Introduction

Cathodic protection!!! Sounds rather mysterious, doesn't it? Like some sort of old-age, social security program or perhaps some private policing agency. However, such is not the case. In this article I shall attempt to take some of the mystery out of cathodic protection by providing answers to some of the basic questions you may have formulated regarding this subject:

1. What is cathodic protection?
2. How does it work?
3. How is it accomplished?
4. What can it do for you or, if you prefer, what can't it do for you?
5. How much does it cost, and how much will it save?

Actually, we would be only kidding ourselves if we promised to provide definitive answers to the above questions. For, in fact, cathodic protection is more of an art than a science, with most of the solutions reached through use of empirical formulas which, in turn, are modified by trial and error applications in the field. Nevertheless, I shall introduce the subject to you, trying to emphasize that cathodic protection is a valuable tool for combating corrosion in a variety of situations.

Let’ begin with the definition. Cathodic protection is defined as the reduction or elimination of corrosion of a metal by making current flow to it from an electrolyte. We will analyze the definition a bit and, hopefully, you will gain a better understanding. Perhaps this analysis can be best accomplished by a brief look at the electrochemical theory of corrosion.

Corrosion Theory

Basically, there are only two types of corrosion, with many variations of these two types. One basic corrosion type is the galvanic or local cell corrosion, while the other is referred to as either electrolytic or stray-current corrosion.

Galvanic corrosion is a self-generated reaction resulting from differences in potentials when metal is placed in an electrolyte. Potential is the amount of energy a metal possesses. Take steel for instance. Steel is not found naturally

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but is an alloy made from iron that occurs naturally as iron ore. Making steel from iron ore requires vast amounts of energy. Although most of this energy is lost in the form of heat, some is stored in the steel as chemical energy, and this is the potential of the alloy. In nature, energy tends to be lost as it runs “downhill” to its natural condition. Corrosion is the result of the tendency of metals and alloys to revert to their natural state. Metals and alloys corrode, with their corrosion products being quite similar to the natural ores from which they are made. An electrolyte, on the other hand, is any substance capable of conducting electricity. An ordering of metals listed according to their potentials in a particular electrolyte is referred to as a “galvanic series.” The galvanic series for metal and alloys in seawater are shown below.

Galvanic series of some commercial metals and alloys in seawater

Active or anodic	Magnesium Magnesium Alloys Zinc Galvanized Steel
	Aluminum 1100
	Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)
	Mild Steel Wrought Iron Cast Iron
	13% Chromium Stainless Steel Type 410 (Active) 18-8 Stainless Steel Type 304 (Active)
	Lead-Tin Solders Lead Tin
	Muntz Metal Manganese Bronze Naval Brass Nickel (Active) 76 Ni-16 Cr-7 Fe Alloy (Active)
	60 Ni - 30 Mo - 6 Fe - 1 Mn
	Yellow Brass Admiralty Brass
	Red Brass Copper Silicon Bronze
	70:30 Cupro Nickel G-Bronze Silver Solder Nickel (Passive) 76 Ni - 16 Cr - 7 Fe Alloy (Passive)

Galvanic series of some commercial metals and alloys in seawater (continued)

Active or anodic (continued)	13 % Chromium Stainless Steel Type 410 (Passive) Titanium 18-8 Stainless Steel Type 304 (Passive) Silver
Nobel or cathodic	Graphite Gold Platinum

Dissimilar metals coupled together, as well as variations in the existing conditions on the surface of a single metal, can, and often do, result in galvanic corrosion. These variations could include nonhomogeneity of the metal, areas of good and poor coating integrity, stressed and unstressed areas, as well as local differences in the electrolyte. When two dissimilar metals are electrically interconnected and placed in a common electrolyte, the classic corrosion cell, the direct-current battery, is formed. Current is generated and one of the metals corrodes. Whether the current produces corrosion or the corrosion produces the current is parallel to the chicken-egg story, and for our purposes, is immaterial. The metal that corrodes is identified as the anode. The other metal receives protection and is referred to as the cathode. Current passes from the anode to the electrolyte and from the electrolyte to the cathode. The electrical connection between the anode and cathode completes the circuit. What determines which metal corrodes in a bimetallic couple is their relative positions on the galvanic series for that electrolyte. The metal higher or more active on the list, possessing more energy or potential, will be the anode, and it will corrode.

Electrolytic (stray-current) corrosion results from direct current from foreign sources such as a direct-current welder, electric railways, grounded direct-current electric power systems, electroplating plants, or cathodic protection systems entering and then leaving a metallic structure by way of the electrolyte. Again, where the current leaves the structure, we have an anode that corrodes.

The basic difference between the two types of corrosion is the source of the current: galvanic with self-generated currents, and electrolytic with external power source. You will note that the above discussion has been wholly restricted to direct current. One can readily see that with alternating current, the anode-cathode relationship would reverse as the polarity changed 60 times in a second, but reduced corrosion is realized. It has been estimated that a 60-cycle alternating current causes only about 1 percent of the damage produced by a direct current of the same magnitude.

Basis for Cathodic Protection

From this brief review of the corrosion theory, it becomes rather obvious that to eliminate corrosion, the electric current producing the corrosion must be stopped. One method of doing this is by the use of coatings. Dielectric coatings reduce corrosion by impeding the flow of current. If a perfect coating were available and practical, one with infinite durability, excellent bond, 100 percent continuity, and having sufficient electrical resistance to prevent the flow of electric current, no corrosion would occur. Unfortunately, the perfect coating is awaiting development. And thus, cathodic protection is sometimes used to supplement coatings in the battle against corrosion.

Since we have found that electric current can cause corrosion and corrosion can generate electricity, why can’t corrosion be prevented by the use of electric current? This was the thought of Sir Humphrey Davy, an English chemist, who is generally credited with developing the basic principle of cathodic protection and making its first application in 1824. The basic principle is to override, cancel, or negate the natural corrosion current with an opposing current from another source. When sufficient direct current is applied to the structure such that no differences in potential exist between formerly anodic and cathodic areas within the structure, corrosion is arrested. In essence, we are making all points on the surface of the structure a cathode by passing current to it and, hence the title, cathodic protection. Thus, cathodic protection is an active method of corrosion control, employing dynamic potentials to overcome the natural corrosion potentials. Coatings, on the other hand, are passive in that they merely impede the corrosion currents. You can appreciate that, in theory at least, the basis for cathodic protection is relatively simple, although as we will discover later, the practical designs for the various applications can differ substantially and become quite complex.

Cathodic Protection Methods

There are two methods by which corrosion can be controlled by cathodic protection—one being the galvanic or sacrificial anode method and the other being the impressed current method.

In the galvanic anode method, corrosion is controlled by purposely creating a corrosion cell through use of a bimetallic couple. The cell is designed in our favor through careful selection of the anode material so that it is more anodic than the structure to which it is coupled. In this manner, the current will pass from the galvanic anode that sacrifices itself and corrodes. The structure receives current and is protected. Corrosion is controlled, but not stopped, as we have merely transferred the corrosion from our structure to the anode. Both the structure to be protected and the anode must be in a common electrolyte and be connected with an insulated electrical conductor. The insulation is required to prevent corrosion of the conductor and, thus, destruction of the metallic, current-return path.

Common sacrificial anodes used for protecting iron or steel are magnesium, zinc, and aluminum. Of these, magnesium is the most popular because of its greater driving voltage that makes it suitable for use in the higher resistivity electrolytes. Magnesium corrodes or is consumed at the rate of about 17 pounds per ampere-year, zinc at 26 pounds per ampere-year, and aluminum from 6 to 12 pounds per ampere-year.

The impressed current method of cathodic protection uses anodes that are energized by an external, direct-current power source. Since the anodes are not expected to provide the driving potential but are merely used to pass current from the external source on the electrolyte, more permanent-type materials can be used for the anodes, those which are consumed very slowly. These include graphite, carbon, and high-silicon cast iron, which are consumed at rates less than 2 pounds per ampere-year. The power source normally used is a rectifier that produces a direct current (actually rectified alternating current) from an alternating current. Again, the anodes and the structure must be in a common electrolyte and connected together by way of the rectifier with an insulated conductor. Care must be exercised to connect the anodes and the structure to the correct terminals on the rectifier. The anodes are always connected to the positive terminal. If connected in reverse, accelerated corrosion of the structure will be experienced, although you will probably have the best looking anodes in the country.

Each method of applying cathodic protection currents has characteristics that make it more applicable to particular situations than others. Some of the more important of these characteristics are listed below.

Galvanic	Impressed current
No external power required	External power required
Fixed-driving voltage	Variable voltage
Limited current output	Variable current output
Anodes consumed more rapidly	Anodes relatively long lived

With the fixed-driving voltage, the galvanic method is restricted to application in the lower resistivity electrolytes, but the possibility of interference on other structures is reduced. On the other hand, the impressed current method can be effectively used in the higher resistivity electrolytes but can also cause severe interference effects on other structures. Unavailability of alternating-current power may dictate the use of galvanic anodes. Therefore, the method selected is governed by the above conditions as well as other considerations and may turn out to be a compromise decision.

Applications and Limitations

Previously we have found that, theoretically, cathodic protection should be able to protect any metal in any electrolyte. Practically speaking though, for cathodic protection to be successful, we must have:

1. A suitable continuous electrolyte common to both the anode and the structure

2. A method of making current flow in the desired direction (to the structure)

3. A method of getting sufficient current to every point on the surface of the structure

Common suitable electrolytes include soil and water. Structures in air cannot be cathodically protected, although one can argue that the use of metallic zinc or metallic aluminum coatings on steel is a form of cathodic protection widely used in the atmosphere. Iron and steel are the most common materials protected cathodically, although more noble metals can be protected. Cathodic protection can be used on new structures and is often the most economical method of controlling corrosion on aged structures. Typical applications include protection of:

1. Exterior surfaces of buried tanks and pipelines
2. Interior surfaces of water tanks
3. Exterior surfaces of well casings
4. Tower footings
5. Watergates
6. Steel piling

One must remember that cathodic protection cannot plate metal on a surface; that is, it cannot replace metal lost to corrosion. In fact, in some reported cases, an aged pipeline will disclose a new leak soon after cathodic protection is applied. This is generally due to loosening of corrosion products that formerly were effectively sealing an existing hole.

An anode is limited to protecting only metal which it can “see”; the protective current cannot “reach through” a pipe to protect the interior since they are not in the same electrolyte. In other cases, one structure may shield another such that the protective current cannot get to the shielded structure.

Protecting the interior surfaces of pipelines, although possible, is normally not practical. However, this is sometimes done by some industries through use of special designs.

Bureau of Reclamation (Reclamation) practice presently calls for employing cathodic protection when serious corrosion problems are indicated by previous experience or if a corrosion survey indicates an aggressive environment. In Reclamation applications, cathodic protection is almost always considered for use with high-quality coatings. When used in conjunction with coatings, only the bare spots and holidays require protection, thus reducing the power requirement tremendously when compared to protecting the entire surface of uncoated metal or say 50 percent of a poorly coated structure. Power costs make cathodically protecting an uncoated or poorly coated structure extremely expensive and, thus, the application of a high-quality coating is normally justified except in special cases. Cathodic protection is most often applied to an existing structure when an anticipated corrosion problem develops long after construction.

Design

Because of the differences in the requirements for cathodic protection systems necessary to achieve protection, each system requires customized design. Rules are avoided simply because there are none applicable to every situation. The trick is to determine how much current is required and how to get it to every point on the surface of the structure. Obtaining this information usually requires testing to determine:

1. The electrical continuity of the structure and its geometry
2. The resistance of the structure
3. The electrical characteristics of the electrolyte (resistivity)
4. The polarization characteristics of the structure

Even after the most thorough preliminary testing and careful design, each system requires checking and adjusting by trial and error after installation.

Criteria

The most commonly accepted criteria for protection of steel are the structure-to-electrolyte potentials of a negative 0.85 volt or more negative as referenced to a copper-copper sulfate electrode. This electrode consists of a copper rod immersed in a saturated copper sulfate solution. The solution is allowed to leach out through a porous plug to the electrolyte. This cell is sufficiently stable for most cathodic protection work. The potential is measured by means of either a high resistance voltmeter or a potentiometer voltmeter.

When cathodic protection is used in conjunction with coatings, care should be exercised to maintain the protective potential within a range of from negative 0.85 to negative 1.50 volts. Overprotection can result in disbonding or stripping of some coatings through hydrogen evolution at the metal-coating interface.

Operation and Maintenance

Once cathodic protection systems have been designed, installed, and adjusted, they, of course, should be properly maintained for trouble-free service. Accurate and complete records should be maintained of the output currents of galvanic anodes and the output voltages and currents on impressed current systems. The record of the current outputs is required for galvanic anode systems to estimate anode life expectancy. Leads should be checked periodically to see that they, as well as their insulation, are intact. Rectifiers for impressed current systems should be kept free of debris, and their output should never exceed their rated capacities in either voltage or current. Any large changes either in current or voltage indicate a need for further investigation. Also, about once a year, a potential survey should be conducted to determine if adequate protection is being obtained.

Cost and Savings

There is no general rule that applies to cathodic protection costs and savings. However, there are several parameters affecting the cost of cathodic protection:

1. Size and shape of structure to be protected. – It is, of course, obvious that, other considerations being equal, a small structure would be cheaper to protect than a large structure and that simple shapes are more easily protected than complex shapes.

2. Electrolyte characteristics. – Less power is required in the lower resistivity media and, thus, almost always ground (anode) beds are installed in the lower resistivity soils.

3. Type and integrity of coating. – Protecting surfaces coated with highly insulative coatings such as coal-tar enamel would be less costly than protecting surfaces coated with cement mortar. The coal-tar-enamel-coated structure requires protection only at the pinholes and bare spots, as contrasted with the highly conductive (when wet or damp) cement-mortar-coated structure consuming current over its entire surface.

4. The cost of available power would, of course, be an important consideration.

Review and study of some of the literature and reports indicate that the range in costs for installation of pipeline cathodic protection systems varies considerably from a low of $0.01 per square foot to as much as $0.20 per square foot, with the average being perhaps $0.07 per square foot. This at least should give you an idea of the order of magnitude of cathodic protection costs.

The savings can best be illustrated by examples. The initial cost for installing the cathodic protection system for the Panama Canal gates reportedly was less than one-half of 1 percent of the cost of gate replacement. One also hears stories in which one leak in an oil line can eat up the entire year's profits.

Closer to home, water, of course, is a very valuable commodity, particularly to farmers who need one last watering to mature their crops. What kind of savings do you think they would assign to corrosion prevention, particularly if a hole develops and it turns out to be their share which is going down the drain or, worse yet, flooding a ready-to-harvest orchard? I have the feeling they would assign a rather high figure, don't you?

Although one could probably assign astronomical values to corrosion costs, to be meaningful, the cost should be determined using a sound basis. Some of the costs attributable to corrosion are shown below.

The direct costs are determined rather straightforwardly:

1. Cost of product lost through leaks
2. Loss of revenue
3. Cost of labor and materials to repair the leak
4. Damage to landowners for land and excavation
5. Cost of overhead, engineering, and testing in leak repair
6. Increase in annual depreciation due to shortened life

On the other hand, indirect costs are difficult to assess. This is true because of their intangible nature. What value do we place on loss of life or limb? Or the psychological distress associated with unpredictable, catastrophic failures? These are the things to be considered in assessing the indirect costs of corrosion.

From the above discussion, one can see that assigning costs and savings to corrosion control can become quite complex. But in this day and age, when emphasis is placed on economic justification, you must be armed with a sound cost and savings estimate that considers the above as well as other factors in presenting a proposal to management. The days are gone when you could merely say: "I think it would be well worth the investment."

Summary

To summarize, cathodic protection is a highly adaptable and effective means of corrosion control. Although the theory is relatively simple, the practical applications are usually quite complex, and so this method of combating corrosion cannot be applied indiscriminately or without careful investigation. However, when properly applied, cathodic protection can be one of the more economical corrosion control methods and, as such, you should keep it in mind for augmenting coatings in the never-ending battle against corrosion.

Irrigation Pump Intake Structures for Shallow Meandering River Applications

by Jim Weigel and Mark Spears

Introduction

In 2000, the Bureau of Reclamation's (Reclamation) Dakotas Area Office entered into a cooperative agreement with the North Dakota State University (NDSU) Extension Service to promote water conservation activities. A remarkable outcome of this cooperative effort was the development of two innovative small irrigation river intake devices.

The development of the intake devices is the subject of an Association of Agricultural Engineers Paper (Number MBSK 02-304), which was authored by the NDSU students and faculty responsible for developing the devices. An informational brochure on the intake devices was also published by the NDSU Extension Service. This article's description of the devices and associated development effort is based on, and in large part is taken from, these documents with the permission of the authors.[1]

Two types of intake devices, floating and submersible, were researched and developed by NDSU students and faculty, and prototypes have been in operation at sites on the Heart River in North Dakota since 2002. The project was initiated in an effort to address common pump intake related problems being experienced by many of the irrigators along the Heart River.

Many of the Heart River irrigators are faced with difficulties in supplying an adequate volume of water for their irrigation systems, frequent intake screen plugging, and pumping riverbed sediment. The shallow water depth, meandering channel geometry, and suspended/floating debris present a never-ending battle for the irrigators. These problems are primarily the result of changes in the river channel that have occurred since the intake structures were constructed. Significant investments were made to install power supplies to the sites. The combination of high relocation costs and potential environmental constraints often preclude construction of new intakes at more attractive sites. Commercially available and farmer designed intakes have been tried over the years by irrigators with limited success mainly due to the shallow water depth.

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[1] American Society of Agricultural Engineers Paper Number MBSK 02-304. Authors: Thomas F. Scherer, Extension Agricultural Engineer; Lowell A. Disrud, Associate Professor; Ryan M. Waters, Engineering Technician; and Andrew J. Poeckes, Engineering Technician.

Following installation and initial testing of the prototypes in 2002, local irrigators were invited to participate in a field tour of the prototype sites, which was sponsored by Reclamation, NDSU, and the Lower Heart River Irrigation District. Response to the devices was extremely favorable. Two local irrigation equipment suppliers are currently fabricating the devices, and approximately 10 units are presently in operation. Some of the devices have been constructed by NDSU students, and some were constructed by the irrigation equipment suppliers.

Design Considerations

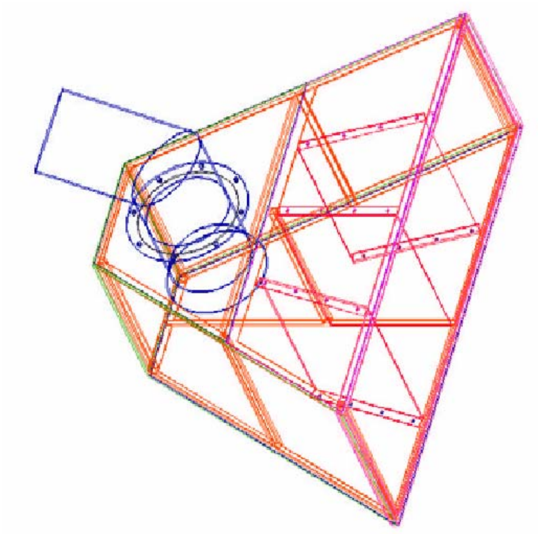
The two types of intakes (floating and submersible) were constructed to provide irrigators with alternative designs to best fit their needs. The main focus during the design process was to decrease the approach velocity of the water as it entered the intake structure. This would control formation of vortexes and prevent air intake, minimize sediment and debris intake, and minimize intake hydraulic head loss. Increasing the screen area where the water enters the intake and positioning the entry screen a sufficient distance away from the suction pipe would decrease the approach velocity of the water. The optimal region to draw water from a shallow river is 3 inches below the surface to 4 inches above the riverbed (approximately). Drawing water from this region helps prevent floating debris and suspended sediment near the riverbed from entering the intake or plugging the intake screen. To pump water from this region, the water must be drawn laterally. This can be accomplished by positioning rigid structures above and below the suction pipe entrance. The rigid structures restrict the intake of water from near the surface and near the river bottom.

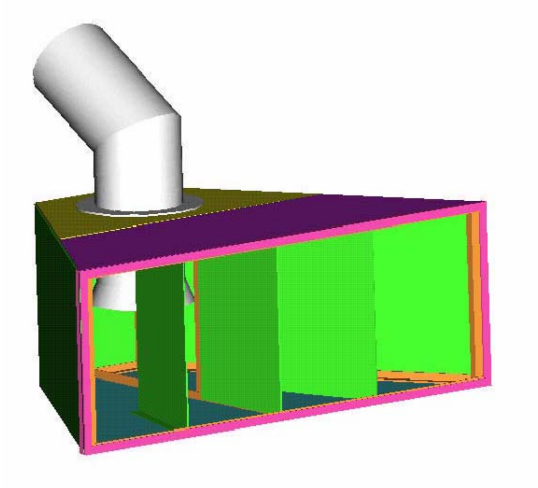
Submersible Intake

Construction of the submersible intake consists of an angle-iron frame, aluminum vanes, an elbow (can vary from 20° - 30°), and an aluminum outer shell. For proper installation, the bottom of the intake must lie flat on the riverbed with the screen parallel to the river current. The current of the river will act as a “natural screen cleaner” if the intake is positioned at the edge or directly in the river’s current. The velocity of the water entering the intake should be less than the velocity of the current, thus the river’s current will carry sediment and debris away, limiting the amount entering the pumping system.

Installation Requirements:

- Intake must rest flat on riverbed
- Angle from water surface to suction pipe required (elbow angle)
- Intake must be positioned parallel to river’s current
- Intake must be positioned at the edge or directly in river’s current





Advantages:

- Decreases approach velocity of water
- Reduces amount of sediment introduced into system
- Screen requires less cleaning
- Intake positioning to current acts as self screen cleaner
- Water is drawn vertically
- No vortexing
- Operates efficiently in 16 inches of water

Disadvantages:

- Time required for initial installation
- Must be positioned directly in or at the edge of river's current
- Weight of intake (130 pounds)

Estimated cost of prototype: $325.00

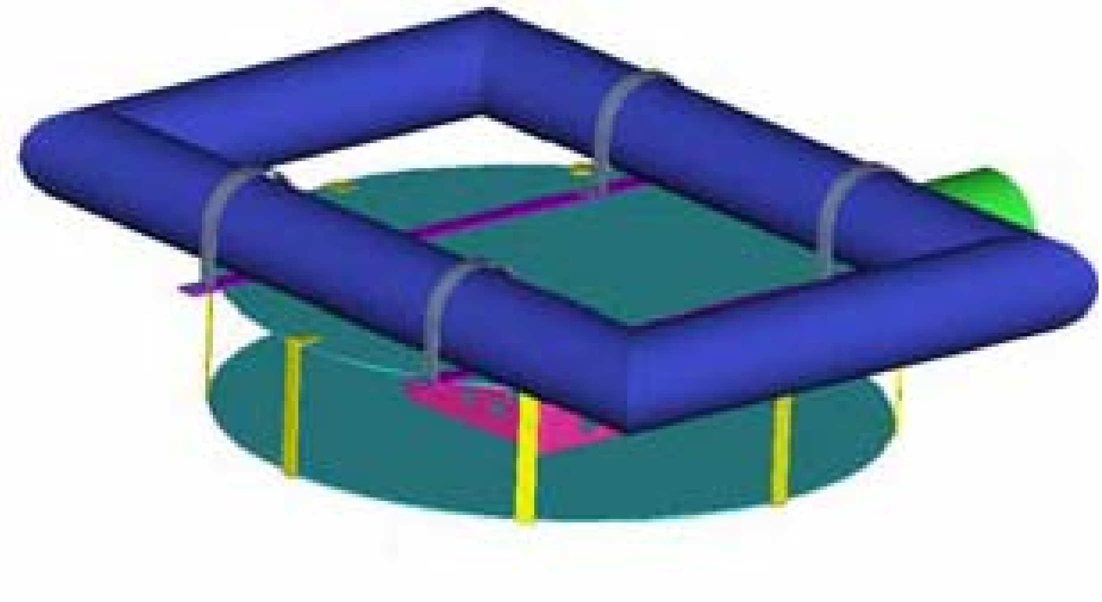
Estimated time to construct: 9 hours

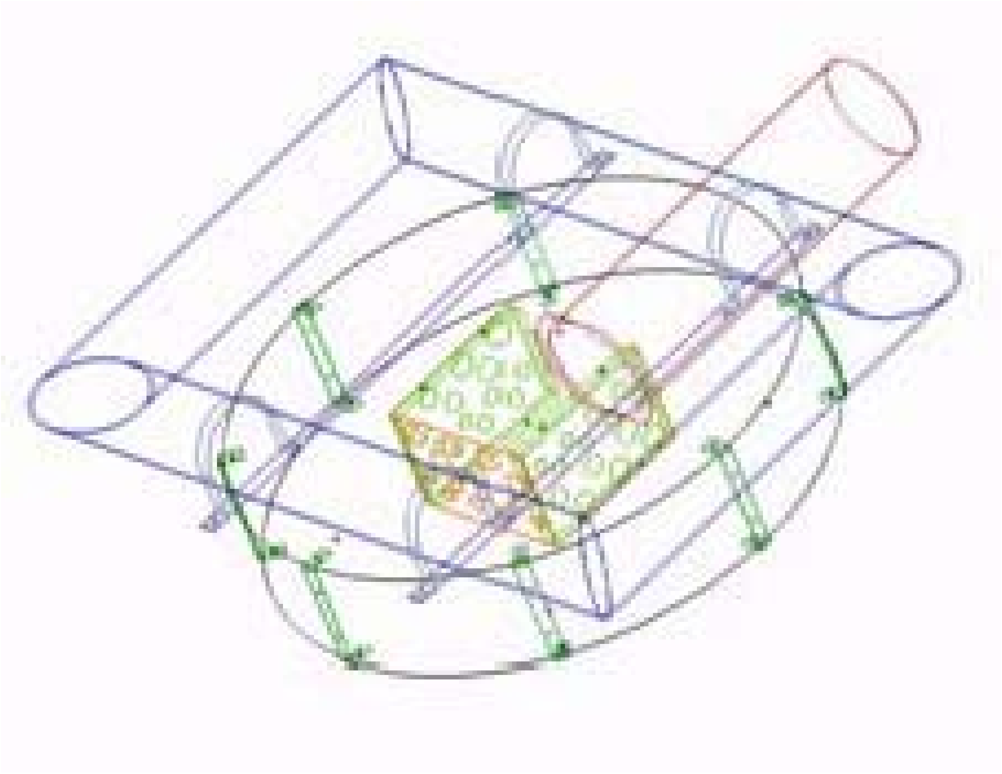
Approach velocity @ 1,600 gpm about 0.82 ft/s
800 gpm about 0.41 ft/s

Operating range: Up to 1,600 gpm

Floating Intake

The floating intake is a lightweight aluminum structure with sealed polyvinyl chloride pipe providing floatation. The intake has an inside rectangular box about 1 foot by 1 foot with circular openings of various size to provide a uniform flow distribution into the suction pipe. Using a distribution box and locating the screen a sufficient distance from suction pipe allows for control of the intake velocity at the screen. The design of the float positions the upper portion of the intake 3 inches below the water surface allowing water to be pumped from the optimal region of the river. With a flexible suction hose, the irrigator is not limited to one location, allowing the intake to be oriented to a preferable setting.





Installation requirements:

- Use of flexible suction hose

Advantages:

- Works efficiently in 12 inches of water
- Decreases approach velocity of water
- Decreases approach velocity of water
- Reduces amount of sediment introduced into system
- Screen requires less cleaning
- No vortexing
- Raises and lowers with the water level
- Installation time is minimal
- Flexible hose allows for optimal positioning

Disadvantages:

- In the event of a rapid increase in water level the intake would have to be removed

Estimated cost of prototype: $525.00

Estimated time to construct: 6 hours

Estimated time of installation: 45 minutes

Approach velocity @ 1,600 gpm: 0.72 ft/s
800 gpm : 0.36 ft/s

Operating range: Up to 1,600 gpm

Comparison to Conventional Intake

NDSU measured flows and pumping plant efficiency before and after replacement of the conventional screen with the new design. The results are shown below.

Submersible intake serving a field flood irrigated by gated pipe:

- Landowner observed an approximate 75 percent reduction in accumulated sediment in gated piping with new intake.

- Flowrate increased by 50 gpm.

- Need to clean screen has decreased from 1 to 2 times per day to once every 3 days.

Floating intakes—one serving a field flood irrigated by gated pipe and one serving a field irrigated by a center pivot:

- Landowners observed a reduction in accumulated sediment in systems that will reduce wear on the pump and sprinklers, thereby maintaining efficiency and application uniformity.
- Flowrate increased by an average of 100 gpm.
- Landowners stated the new intakes improved overall system performance by making their systems more reliable and by maintaining flow rates because of less debris accumulating around the intake screen.

Conclusion

The conditions that have resulted in the Heart River irrigators' need for alternative types of intake devices are not unique, and it is suggested that significant potential exists for application of these devices in other areas. Reducing the intake velocity of the screen and pulling the water in horizontally was the key to overcoming problems of screen plugging, pumping sediment, and vortexing. The new intake screen designs resulted in increased pump flows, increased pumping plant efficiency, reduced labor to clean screens, and improved application efficiency. The straightforward and low-cost design of the screens enables irrigators to construct it without specialized equipment. The feedback from irrigators is that they believe the screens to be cost effective. For additional information on this topic, the reader should contact:

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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.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

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