SEDIMENT SOLUTIONS SYSTEM - NEW MAINTENANCE OPERATIONS AND RIDGED RECHARGE BASIN FLOORS MAXIMIZE INFILTRATION EFFICIENCY[1]

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Abstract: Ridges located in the bottom of a recharge basin and furrows adjacent to the ridges facilitate cost effective maintenance of the basin using the naturally occurring forces of gravity, water currents, and wave action. The ridges are normally formed from material taken from the furrows into shapes that facilitate sediment migration from the ridges into the furrows. While submerged, sediment settles on the ridges and furrows. The sediment on the submerged ridges tends to migrate toward and into the furrows. The basins are routinely dewatered allowing wind driven or induced wave or water action against the sides of the ridges to wash the sediments from the ridges into the furrows, thereby maintaining the permeability of the ridges.

Recharge Basin Clogging Problems and Common Maintenance Practices

Sediments and clogging layers are inorganic and/or organic particles that settle or form on the wetted surface of a basin during its filling and operation (Bouwer & Rice, 1989). The clogging effects of even thin layers of sediment can be profound. The common methods of maintaining basins and controlling sediments clogging effects are expensive and time consuming. All the methods first require that the basin be drained and dried. After drying, medium to heavy equipment is normally used to work the basin's bottom.

The "dry and crack", sometimes called the "chip" method is employed by allowing the sediment to dry and crack, thereby opening spaces between the chips. The basin is then refilled and brought back into operation till the next draining and drying is performed.

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The “Shallow Mixing” method normally involves using medium weight equipment, after drying, to mix the sediment layer with the upper several inches of basin bottom. This mixing disperses the thin sediment layer and is effective until the increasing concentrations of sediment material make removal of the mixed layer cost effective. Compaction is also a concern. The use of the equipment often creates a significant compaction layer just beneath the mixed layer.

The “Deep Mixing” method requires the sediment layer to be mixed several feet and up to four feet or more deep using heavy equipment. The compaction layer does not form behind the deep ripping operation. However when the material becomes clogged and must be removed the quantity is significant and the operation often becomes cost prohibitive.

Both the shallow and deep mixing methods can lead to organic clogging of the mixed area of the basin. Since many spreading basin recharge efforts occur in arid climates, single cell algae is normally prolific in the ponded water. The residual of this significant biomass is responsible for most of the organic component of the basin sediment. The sediment forms an increasingly thick and effective clogging layer. The clogging effect is most profound in smooth and flat-bottomed basins.

When mixing is performed to disperse the clogging layer of sediment, the organic loading is dispersed within the mixed zone. With repeated mixings, the organic concentration will likely reach a level able to support significant anaerobic activity. Anaerobes normally produce slime and have been found to cause significant clogging in basins where shallow mixing was employed over several years. Anaerobic clogging of deep mixed basins has also been observed. Deep mixing and deep anaerobic clogging are most often experienced in municipal wastewater treatment operations.

Some urban flood control basin operators have elected to employ what might be termed the “Minimum Scraping” method. Herein, the sediments potentially contain pollutants and more than the bare minimum excavation of basin material is undesirable. The sediments are thinly scraped and windrowed using a motor grader then removed from the basin floor. The compaction of the basin floor becomes significant with repeated scrapings. However, the compacted bottom is not ripped or loosened since to do so would result in the creation of an uneven bottom surface requiring subsequent removal of the excess material during the following cleaning.

An improved system is needed for controlling sediment in basins that is beneficial for both percolation rates and management of insoluble contaminants. Such an improved system should reduce the frequency of basin maintenance, the cost of that maintenance and the need to dispose of unwanted basin materials. Additionally, the improved system should be cost effective for installation in new basins and easily adaptable to existing basins. The system should minimize labor costs and the amount and frequency of basin downtime.

The "Percentage" Factor

The permeability of a basin is usually governed by the degree of sediment clogging at the surface, or plow-pan compaction within the first few feet and by the characteristics of the much deeper underlying strata or material. Often an aquitard of poorly permeable material such as clay is present at depth and above the groundwater table. A freshly scraped and ripped basin will have a percolation rate equal to the permeability of the geology and hydrogeology beneath the surface. Only in rare circumstances is the permeability of a basin governed by the unclogged material at the near surface. In other words, it would be rare for the upper, say 3 feet of a basin, to be fine grained while the material below and to the water table, to be coarse. More commonly, the upper material is coarser than some deeper layer of relatively fine material. The deeper and finer material will govern the permeability as long as a clogging sediment layer does not form over a significant portion of the surface.

For a typical basin to maintain its maximum or near maximum permeability, only a percentage of the surface need be sediment free. That percentage is estimated by evaluating the unclogged surface materials' permeability compared to the permeability of the subsurface materials or limiting conditions. A successful sediment control system would ensure an adequate surface area be maintained sediment free and non-clogged. If a percentage, such as 5 to 20 percent, of a typical basin's surface could remain un-compacted and effectively sediment free the basin's recharge rate would be maintained at or near its maximum.

A Sediment Solution to Maximize Permeability and Minimize Clogging Maintenance

Through four years of research and development a highly successful system has emerged. Large ridges provide side slope areas that can be maintained to remain relatively sediment-free and therefore, permeable. Wide flat furrows, between the ridges, collect the sediment and become clogged. The continued permeability of the ridge areas far outweighs the consequential clogging in the furrow areas. Using natural forces such as gravity and water shear to migrate clogging sediments and layers completes this system. This system significantly reduces the clogging effects of sediment at considerable savings compared to currently employed methods. The uses of ridges and furrows in basin bottoms, together with newly developed maintenance practices, have successfully demonstrated immediate benefits and promises to provide long-term value. To date, over 30 basins have been fitted with ridges and furrows and effectively maintained with excellent results. Percolation rates have been maintained at or near maximum historic rates without the need for periodic basin drying or the use of equipment. The value of reduced downtime can be quite significant.

The Development of the New System

Sediment tends to settle and migrate to the lowest elevation available, all other factors being equal. After several basins were scraped and ripped, a motor grader was used to excavate 6 to 9 inches of material by windrowing and shaping side slopes parallel to one another. The ridges were constructed with the motor grader. Furrows of 10 to 12 feet in base width on 30-foot centers provided a sediment collection area and provided adequate width to operate a motor grader and/or paddle wheel scraper when removing the future accumulated fines. After several iterations, a typical design emerged for the local conditions. (Peyton, 2001) A simplified cross section is depicted below in figure 1.

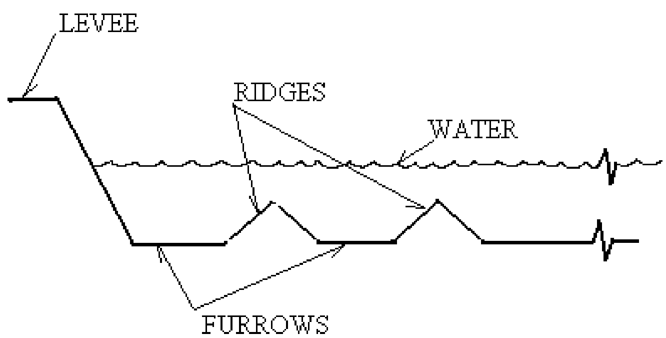

Figure 1. **The simple profile of ridges and furrows near the levee edge of a typical basin. The ridges are submerged in normal operation.**

The ridges worked well and refinements were developed as percolation rates and field observations became available. The inflow rate approached its maximum of 60+ acre-feet per day and was sustained without routine drying and mechanical maintenance. See figure 2.

Background

Leaky Acres is a 150+ acre wetted groundwater recharge facility in Fresno, California installed in the 1970's. The alluvial stratum at Leaky Acres contains two silt-clay primary aquitards (fine, tight and poorly permeable layers) located at approximately 30 and 60 feet below ground surface (BGS) (Nightingale & Bianchi, 1973). The standing groundwater level is normally at about 105 feet BGS. The aquitards limit percolation of the surface waters applied to between 0.2 and 0.5 ft/d. All of Leaky Acres' surface soils are sandy to silty sand with permeability significantly greater than that of the aquitards. The challenge became to develop a low maintenance facility without compromising effectiveness. The City has used disking, ripping, scraping and combinations thereof to control and/or remove the 'clogging fine layer' which developed each recharge season with varying degrees of success. The cost of annual or semi annual mechanical maintenance methods had been considerable. The cost for mechanically maintaining a typical 10-acre basin was approximately US$200 and US$8,000 for disking and scraping respectively. Disking was performed annually and scraping was performed approximately every 20 years so the annual cost was approximately US$60/acre.

The source water is available 9 to 11 months per year with a required downtime for ditch system maintenance during winter. Basins need to be drained and dried to accommodate the mechanical maintenance. The basin to be maintained would be taken out of service during a warm and dry period, normally summer, for approximately 45 days per year. The basin would be unavailable to percolate 0.35 acre feet per day per acre over this period amounting to over 2,500 acre feet per year of water not percolated.

The annual value of the water not recharged at the Leaky Acres facility due to maintenance was approximately US$270,000 or US$1,800 per acre. The value of the water not recharged during maintenance far exceeded the cost of the maintenance. Until now the lost recharge due to downtime for maintenance and the costs for the maintenance itself were unavoidable and therefore accepted.

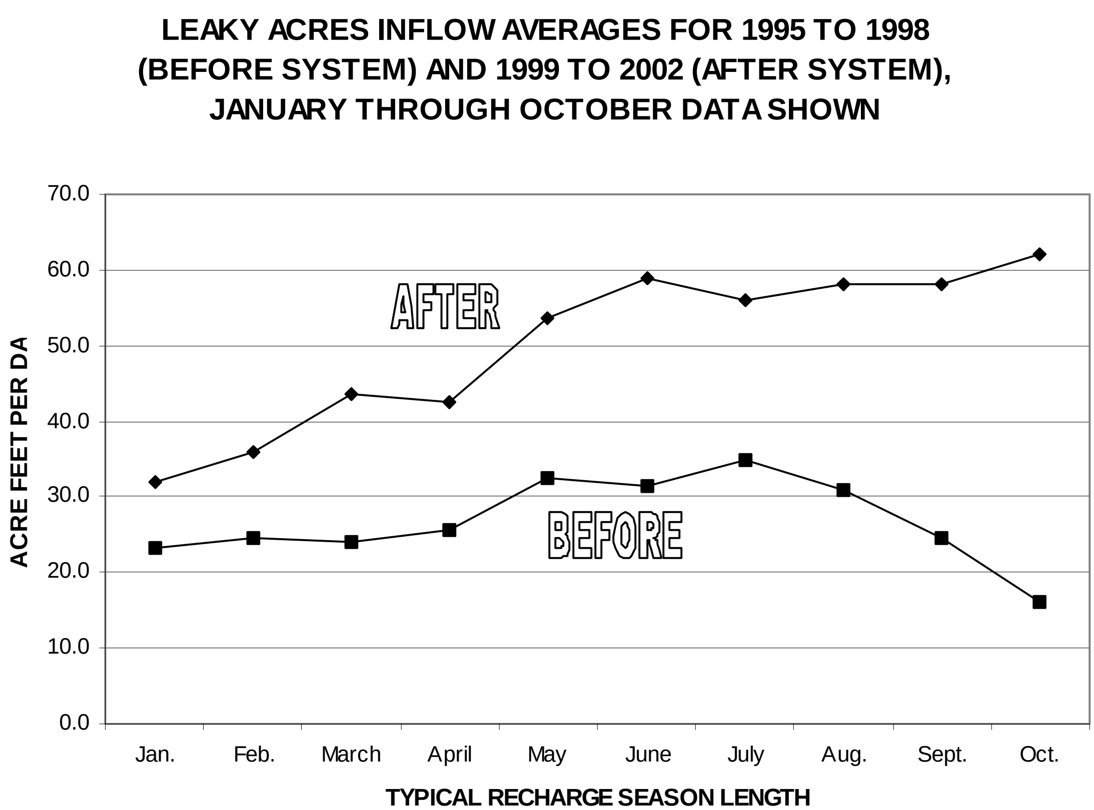

Figure 2. This data is the inflow average of the four years before the system was in

place compared to the inflow average of the recent four years after the system was installed and operating. Leaky Acres basins are normally operated full to maximize infiltration. Notice the effect of clogging near the end of each recharge season before the system was used. Notice the improved and sustained average seasonal inflow rate after the system was in place. Not shown are the significant maintenance cost savings with the system in operation.

Sediment and Insoluble Contaminant Control

The furrow area becomes the collector for the sediment and therefore becomes less and less permeable. This loss of permeable area is significantly offset by the sustained permeability of the ridge side slopes. The sediment building in the furrow area has potential benefit when controlling insoluble contaminants. The insoluble contaminants will collect in the increasingly impermeable furrow area and become trapped over time while the basin remains in operation at or near its maximum infiltration rate. The insoluble contaminants can be reduced and/or oxidized over time using natural processes or by introducing reactants.

Maintenance With Less or No Equipment

The steepness of the ridge side slopes effects the migration of sediments toward the furrow while the ridges are in use and submerged. The sediment less likely to impact the submerged steep side slope and the maintenance (de-sedimentation) of the ridges is simpler and less expensive than existing practices. Relatively clean surface waters contain few suspended solids (SS), are low in nutrients and promote limited algae growth. Therefore in most surface water recharge applications, the submerged ridges will sustain their permeability with only periodic dewatering for maintenance. Operating the water level just above the ridge's top will take advantage of surface wave energy to minimize the accumulation of fines on the upper areas of the ridges.

Municipal and some industrial wastewaters contain high TSS concentrations and/or contain algae supporting nutrients such as nitrates and phosphates. Phosphates can sometimes be economically precipitated with coagulants such as alum or polymers to control algae growth. Over time, the inorganic and organic loading can impact the permeability of the submerged ridges. High percolation rates also impact the tendency toward clogging of the submerged ridges.

When deemed necessary, the ridges can be maintained in several ways to migrate the sediments into the furrow area. One effective means of washing is to lower the water level, by reducing or shutting off the inflow rate. As the water level reaches the top of the submerged ridge and descends along the side slope, wind-induced waves re-suspend many or all of the accumulated sediments. The suspended sediments migrate toward and ultimately into the furrow area as the water level continues to descend toward the furrow. Wind driven waves have benefits and a few disadvantages. The wind is often periodic throughout the day while the infiltration rate is constant. The result can be the formation of 'shelves' on the side slopes and unwanted erosion. With excess and/or periodic erosion, the eroded material covers some submerged sediments on the ridge slope. Operators should observe the effectiveness of the wave action and make water level adjustments as necessary. The washing should occur without excessive wind to avoid excess erosion.

It has been determined that ridge orientation to prevailing winds can be important if frequent wind driven wave washing is desired. Where winds are light or unpredictable, the ridges should not be oriented parallel to the wind direction, Where winds are predictable and have speeds in excess of about 14 mph, the ridges can be placed parallel to the wind direction with good results. The waves can be created by other means as well. One creative idea is to use a jet ski or flat bottomed boat to create waves to better control the amount and duration of washing performed.

The use of waves or rain is highly effective and best employed before sediment builds to a thickness, normally ¼ inch, or consistency which resists effective washing. Conditions vary therefore and it is important to perform an initial site assessment, create a design and operations plan before construction of a sediment control system. The system should be evaluated periodically for up to 3 years to refine the operations plan as necessary.

A ridge-cleaning tool (RCT) is being developed to remove the sediment and surface fines that collect on ridges where dewatering for wave washing or drying is either impractical or not cost effective. The RCT will be used while the ridges are submerged and will move accumulated material from the ridge surface toward and into the furrow area at the base of the ridge. Like wave washing, the RCT will use the available force of gravity to effect an efficient and reliable sediment control system. The prototype of the RCT, currently under construction, will be used with an outboard motor powered boat. The RCT will loosen the surface clogging layer(s) and direct the surface layers toward the furrow area using shear, water and gravity forces. For more information regarding the RCT, contact the author. A U.S. patent application for the RCT is expected within a year of this publication.

In situations where neither wind or rain is a predictable tool and where the use of a wave generating device or ridge cleaning mechanism is unavailable or prohibitive, the ridges can be dried as in the crack and chip method and the sediments moved to the furrow area using hand held leaf blowers, rakes or other low tech devices.

In all these routine maintenance scenarios, medium or heavy equipment is rarely needed. This has many significant advantages, perhaps the most significant, where the value of water is high, is the ability to operate a recharge facility year round without drying the basin. During the washing period the basin is dewatered to just above the furrow elevation and recharge is slowed but continuing and air entrainment in the vadose zone is minimized. When a basin is dried, air enters many of the soil pore spaces, causing air clogging until the air is displaced by water when infiltration is resumed. This air clogging phenomenon is most noticeable in large spreading applications and can require months of recharge before the maximum infiltration rate of the large spreading operation is achieved. The air clogging effect can be seen in figure 2 as a gradual rise in inflow rates over the initial several months of Leaky Acres seasonal operation.

Another significant benefit is the obvious savings gained by not using medium and/or heavy equipment, labor, fuel, etc. Compaction of the permeable surface becomes a non-issue with the lack of machinery on the ridges. When the accumulated sediment builds to a point where removal is cost effective, the equipment needs only operate in the furrow area where permeability and compaction are not important. It is emphasised that the furrow area should be perceived as an impermeable sediment collection area capable of containing non-soluble contaminants/pollutants.

The sediment should be removed when the accumulated sediment significantly impinges on the side slopes and begins to reduce basin infiltration. There may also be circumstances where the non-soluble contaminants require removal and sediment removal is economical.

Results

The use of the sediment control system has shown two marked improvements compared to previous practices. The first is that infiltration remains at or near the maximum value for a given basin as long as occasional dewatering for wave washing, not drying, is performed. The second is the lack of mechanical equipment needed for mixing or scraping, including ripping to loosen the subsequent compaction created by heavy equipment.

The system is the use of specially designed ridges and furrows. The ridges vary in height and width depending on the basin depth, available soil, operational objectives/limitations, pollutant considerations and subsurface conditions.

Conclusions

The use of this system has been proven effective in controlling sediment clogging of the ridge side-slope surface. The ridges remain relatively sediment free while submerged and removal of any problematic ridge sediment is normally accomplished using waves or rain during and after dewatering. With routine wave washing, the surface of the side-slopes normally become coarser over time due to soil maturation. The operation of the water levels and field observations are important. Where basins are deep, water levels are kept high and/or percolation rates are rapid, ridge clogging becomes more likely. Devices such as the ridge-cleaning tool may be economically employed to sustain basin infiltration rates where conditions warrant.

The sediment migrates into the furrow area where it builds up a relatively impermeable sediment mat. This mat can be useful for containing non-soluble pollutants and affords an opportunity for in-place treatment of the non-soluble pollutants or contaminants. The relatively impermeable nature of the maturing mat and its ability to contain non-soluble pollutants and resist leaching will likely benefit various types of basin applications.

The use of machinery is significantly minimized since the clogging sediment is normally migrated to the furrow using gravity, wind or mechanically driven waves and/or rain. Equipment to generate waves, such as a jet ski, may be useful where conditions warrant. Equipment to scrape and clean the submerged ridges is being developed for use where applicable. With the lack of typical machinery activities, the permeable areas, the ridges, remain un-compacted for the life of the project. Should the furrows require scraping, the subsequent compaction is inconsequential and perhaps desirable in some cases.

Implementation

The use of this sediment control system is maturing. The opportunities for a variety of applications are emerging. Each opportunity requires evaluation to provide the best available results and therefore the optimum efficiency. To date, this system is actively used in groundwater recharge, storm water control, and municipal treated wastewater infiltration basins.

Knowledge and valuable experience gained during the years of this system's development will be used and added to in future applications. Groundwater quality goals and quantity needs can be coupled with more efficient and better performing water infiltration projects.

This system is U.S. patent pending at this writing. License agreements together with design and operation consultation services are available.

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