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A Study of Methods for Recharge of Aquifers and Porous Asphalt Pavement

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***Abstract*: Ground water accounts for nearly 95 per cent of the nation's fresh water resources. It can stay underground for hundreds of thousands of years, or it can come to the surface and help fill rivers; streams, lakes, ponds, and wetlands. Groundwater can also come to the surface as a spring or be pumped from a well. Both of these are common ways we get groundwater to drink. Groundwater is stored in the tiny open spaces between rock and sand, soil, and gravel. Groundwater can become contaminated in many ways. If surface water that recharges an aquifer is polluted, the groundwater will also become contaminated. Contaminated groundwater can then affect the quality of surface water at discharge areas. Groundwater can also become contaminated when liquid hazardous substances soak down through the soil into groundwater. An aquifer can be formed where groundwater can move rapidly, such as through gravel and sandy deposits. In an aquifer, there is enough groundwater that it can be pumped to the surface and used for drinking water, irrigation, industry, or other uses. Aquifers get water from precipitation (rain and snow) that filters through the unsaturated zone. Aquifers can also receive water from surface waters like lakes and rivers. When the aquifer is full, and the water table meets the surface of the ground, water stored in the aquifer can appear at the land surface as a spring or seep. Recharge areas are where aquifers take in water; discharge areas are where groundwater flows to the land surface. Water moves from higher-elevation areas of recharge to lower-elevation areas of discharge through the saturated zone.**

***Keywords*: Ground water, ground water contamination, ground water recharge, aquifers, porous asphalt pavement.**

1. Introduction

Groundwater is stored in the tiny open spaces between rock and sand, soil, and gravel. Groundwater can become contaminated in many ways. If surface water that recharges an aquifer is polluted, the groundwater will also become contaminated. Contaminated groundwater can then affect the quality of surface water at discharge areas. Groundwater can also become contaminated when liquid hazardous substances soak down through the soil into groundwater. Many processes can affect how contamination spreads and what happens to it in the groundwater, potentially making the contaminant more or less harmful, or toxic. Some of the most important processes affecting hazardous substances in groundwater are advection, sorption, and biological degradation.

Porous asphalt pavements allow for land development plans that are more thoughtful, harmonious with natural processes, and sustainable. They conserve water, reduce runoff, promote infiltration which cleanses storm water, replenish aquifers, and protect streams. With proper design and installation, porous asphalt pavements can provide a cost-effective solution for storm water management in an environmentally friendly way. Unlike conventional pavements, porous asphalt pavements are typically built over an un-compacted subgrade to maximize infiltration through the soil. Above the un-compacted subgrade is a geotextile fabric, which prevents the migration of fines from the subgrade into the stone recharge bed while still allowing for water to pass through. The next layer is a stone reservoir consisting of uniformly graded, clean crushed stone with 40% voids serving as a structural layer and to temporarily store water as it infiltrates into the soil below. Then, to stabilize the surface for paving, a thin (about 1-inch thick) layer of clean, smaller, single-size crushed stones are often placed on top; this is called the stabilizing course or choker course. The last layer consists of one or more layers of open-graded asphalt mixes with interconnected voids, allowing water to flow through the pavement into the stone reservoir. These open-graded asphalt layers consist of asphalt binder, stone aggregates, and other additives. By excluding fines, the open-graded mixture allows for more air voids (typically between 16% and 22% voids).

2. Objectives of study

- To recharge & replenish ground water level.
- Recharges groundwater to underlying aquifers.
- To study porous asphalt pavement its composition, strength & effectiveness.

3. Literature study

A. *Nature & effects of ground water*

Chilton J. described that, water is drawn from the ground for a variety of uses, principally community water supply, farming (both livestock and irrigated cultivation) and industrial processes. Unlike surface water, groundwater is rarely used in situ for non-consumptive purposes such as recreation and fisheries, except occasionally where it comes to the surface as springs. Consequently, ground-water quality assessment is invariably directed towards factors which may lessen the suitability of pumped groundwater with respect to its portability and use in agriculture and industry.

Groundwater occurs in many different geological formations. Nearly all rocks in the upper part of the Earth's crust, whatever their type, origin or age, possess openings called pores or voids. In unconsolidated, granular materials the voids are the spaces between the grains, which may become reduced by compaction and cementation. In consolidated rocks, the only voids may be the fractures or fissures, which are generally restricted but may be enlarged by solution. The volume of water contained in the rock depends on the percentage of these openings or pores in a given volume of the rock, which is termed the porosity of the rock. More pore spaces result in higher porosity and more stored water.

B. *Chemical characteristics of groundwater*

Chilton J. described that, since groundwater often occurs in association with geological materials containing soluble minerals, higher concentrations of dissolved salts are normally expected in groundwater relative to surface water. The type and concentration of salts depends on the geological environment and the source and movement of the water.

A simple hydro-chemical classification divides groundwater into meteoric, connate and juvenile. Meteoric groundwater, easily the most important, is derived from rainfall and infiltration within the normal hydrological cycle. Groundwater originating as sea water which has been entrapped in the pores of marine sediments since their time of deposition is generally referred to as connate water. The term has usually been applied to saline water encountered at great depths in old sedimentary formations. It is now accepted that meteoric groundwater can eventually become equally saline, and that entrapped sea water can become modified and moved from its original place of entrapment. It is doubtful whether groundwater exists that meets the original definition of connate water, and the non-generic term formation water is preferred by many authors. Connate water is, perhaps, useful to describe groundwater that has been removed from atmospheric circulation for a significant period of geological time. Formation waters are not usually developed for water supplies because of their high salinity.

C. *Methods of replenish of ground water*

Kavuri et. al., states that the recharge of ground water occurs both naturally and artificially. The natural recharge occurs through the process of infiltration where the water percolates from the surface to the bed of the aquifer. But due to rapid development and stupendous growth of population in the recent past the areas for natural infiltration have been lessening day by day, hence the scope for natural recharge of the ground water is also declining. Thus anthropological methods have been implemented to supplement the natural process of infiltration. A wide range of techniques are being made use to recharge the ground water artificially. The selection of the technique depends upon the hydrological frame work of that particular area. The various methods can be broadly categorized as follows:

- Direct Surface Techniques
- Direct Sub surface technique
- Combination surface-sub surface technique
- Indirect techniques

Apart from the afore mentioned methods, some conservational structures such as ground water dams, sub surface dykes etc. are also utilized to arrest the sub surface flow. Many other techniques are being followed to interconnect the various fractures in the hard rocky areas to augment the ground water.

D. *Recharge of ground water to aquifers*

An aquifer is an underground geological formation which transmits and contains appreciable quantities of groundwater. Water in the ground travels slowly through pores or fractures, depending on the type of sediment or rock material the aquifer is made of aquifers can vary markedly in the quality and quantity of water they hold and the extent of their connectivity with other aquifers or surface water bodies.

1) *Aquifers*

Bhattacharya A. states that, groundwater is a finite resource. It is replenished only when surface water seeps into aquifers. This process of aquifer replenishment is called recharge. Aquifers become depleted if groundwater extraction rates exceed recharge rates. Aquifer depletion affects communities, agriculture and the industries that rely on groundwater supplies. Depleted groundwater reserves can also affect the environment - for example, by reducing river flows that depend on flows from shallow groundwater, or by drying out ecosystems such as some wetlands that depend on groundwater inputs to maintain water levels, known as groundwater– dependent ecosystems. Like rivers and surface water, aquifers and groundwater can become polluted. This affects communities or businesses that rely on clean water supplies. Also, many environments have evolved to tolerate very specific water chemistry, and changing the chemical make-up of groundwater could cause an entire species to die out.

2) *Artificial recharge methods*

Kavuri et. al., states that the necessity of artificial recharge of aquifers is increasing day by day due to excessive demand of water by the ever-growing population and also because of the scarcity of good dam sites available for construction. The vital purpose of artificial aquifer is to preserve superfluous water to meet the needs of the future generation. It is one of the man made efforts to add water to the aquifers. Hundreds of techniques have been developed in the past few years for the sufficient supply of water for the human use. Thus, the ground water has been considerably amplified and the salinity of water has been declined, thus improving the quantity and quality of water. The artificial recharge methods are proving to be effectual in maintenance and replenishment of the aquifers. Artificial recharge of aquifer is the process of adding water to an aquifer through human effort. The main purpose of artificial aquifer recharge is to store water for later use while improving upon the quality of water. Bhattacharya A. states that, replenishment of groundwater by artificial recharge of aquifers in the arid and semi-arid regions of India is essential, as the intensity of normal rainfall is grossly inadequate to produce any moisture surplus under normal infiltration conditions. Although artificial groundwater recharge methods have been extensively used in the developed nations for several decades, their use in developing nations, like India, has occurred only recently. Techniques such as canal barriers, construction of percolation tanks, and of trenches along slopes and around hills, et cetera, have been used for some time, but have typically lacked a scientific basis (e.g., knowledge of the geological, hydrological and morphological features of the areas) for selecting the sites on which the recharge structures are located.

E. Benefits of recharging to aquifers

Bhattacharya A. gives that the artificial recharge has several potential advantages, namely:

- The use of aquifers for storage and distribution of water and removal of contaminants by natural cleansing processes that occur as polluted rain and surface-water infiltrate the soil and percolate down through the various geological formations.
- The technology is appropriate and generally well understood by both the technologists and the general population.
- Very few special tools are needed to dig wells.
- In rock formations with high structural integrity, few additional materials may be required (concrete, soft stone or coral rock blocks, metal rods et cetera) to construct the wells.
- The quality of the aquifer water can be improved by recharging with high-quality injected water.
- Recharge can significantly increase the sustainable yield of an aquifer.
- Recharge methods are environmentally attractive, particularly in arid regions.
- Most aquifer recharge systems are easy to operate.
- In many river basins, control of surface-water run-off to provide aquifer recharge reduces sedimentation problems.

F. Porous asphalt pavement

Hamzah et. al., described that, Porous asphalt (PA) is an innovative road surfacing technology which allows water to percolate into the PA pavement. The inter-connected voids inside the PA allowed water to infiltrate through the pavement and is usually laid on an impervious compacted base course. Impervious surfaces, such as roadways, roof tops and parking lots resulting storm water runoff and deliver dirt and debris directly into the stream. In turn, the existing impervious surfaces caused ponding water which translates few hours of heavy rain into flash floods. Since the 19th century, most cities of the developed country rely on traditional pipe and open drain network system to mitigate storm water runoff. The captured storm water runoff afterwards distributed to nearby water course and sewer system. Existing impervious surfaces due to urban constructions and implementation of concrete drainage system to provide fast solution for storm water runoff, unfortunately limits the dual purpose of PA.

G. Composition of porous asphalt pavement

Joon Pankaj illustrates that the porous asphalt is produced and placed using the same methods as conventional asphalt concrete; it differs in that fine (small) aggregates are omitted from the asphalt mixture. The remaining large, single-sized aggregate particles leave open voids that give the material its porosity and permeability. To ensure pavement strength, fiber may be added to the mix or a polymer-modified asphalt binder may be used. Generally, porous asphalt pavements are designed with a subsurface reservoir that holds water that passes through the pavement, allowing it to evaporate and/or percolate slowly into the surround soils.

Shukry described that, the porous asphalt has been used widely due to its ability to allow rainwater to drain quickly from the pavement surface through its pore structure. Given this ability, porous asphalt is utilized in wearing courses with approximately 50 mm thickness and placed over the impermeable asphalt surface as a possible solution for road safety improvements in wet conditions and for the reduction of traffic noise. Porous asphalt is designed with open-graded aggregate gradations that consist of a large proportion of coarse aggregates with a limited amount of fine aggregates to create larger quantities of interconnected voids of more than 18%, to allow water to penetrate through the voids. The life of a porous surface is expected to be shorter than that of a conventional asphalt surface because of the deterioration by runoff, air infiltration, subsequent stripping and oxidation, and hardening of the binder.

On the other hand, the open gradation and high air-void content lead the porous asphalt mixture to poor durability due to less stone-on-stone contact caused by the inappropriate gradation and low density in porous asphalt mixture, which results in a lower performance than normal dense-grade mixture. Moreover, the open structure that facilitates water drainage exposes the pores of porous asphalt to air, water, and clogging materials that erode the binder film and eventually affects the strength of the binder aggregate bonding.

Yadu Jeet states that, the permeable pavement can be constructed using pervious concrete, paving stones, porous asphalt or concrete or plastic-based pavers. However, here porous concrete is considered for the construction as it is easily available throughout. Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through. Pervious concrete is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. Pervious concrete is a unique and innovative means to manage storm water.

A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly.

4. Requirement of replenish ground water

Any addition of undesirable substances to groundwater caused by human activities is considered to be contamination. Groundwater contamination is extremely difficult, and sometimes impossible, to clean up. Groundwater is one of our most valuable drinking water resources. It is also very important to many agricultural areas. Since it is filtered through the ground, it is often fresh and cold, and usually cleaner than surface water. Unfortunately, groundwater is threatened every day by people who do not even realize what it is or how they are affecting it. More and more states are adopting laws that govern sources of contamination, like storage tanks, but there is no national policy. The main source of groundwater is infiltration. The infiltrated water after meeting the soil moisture deficiency percolates deeply and becomes groundwater. This process is called recharge. The formation below the earth's surface is divided into two zones by an irregular surface called the water table. At all points on the water table, the pressure is atmospheric. The zone between the ground surface and the water table is called the unsaturated zone. In the zone below the water table all the soil pores are completely filled with water and hence it is called the zone of saturation or the phreatic zone.

5. Ground water contamination

Groundwater contaminants come from two categories of sources: point sources and distributed, or non-point sources. Landfills, leaking gasoline storage tanks, leaking septic tanks, and accidental spills are examples of point sources. Infiltration from farm land treated with pesticides and fertilizers is an example of a non-point source. Among the more significant point sources are municipal landfills and industrial waste disposal sites. When either of these occurs in or near sand and gravel aquifers, the potential for widespread contamination is the greatest. Other point sources are individually less significant, but they occur in large numbers all across the country. Some of these dangerous and widespread sources of contamination are septic tanks, leaks and spills of petroleum products and of dense industrial organic liquids.

6. Ground water recharge

Recharge is the replenishment of water to a groundwater system from the ground surface. It can occur naturally or artificially. Infiltration of rainfall beneath the land surface and its movement to the water table is a widespread form of natural recharge. Aquifers can also be recharged from surface water infiltrating the ground from water bodies such as rivers, creeks, dams and wetlands. It is possible to artificially recharge an aquifer for subsequent recovery or environmental benefit. This is often referred to as managed aquifer recharge (MAR) or aquifer storage and recovery (ASR). In urban areas, MAR can be used to store desalinated seawater, recycled water, storm water and even mains water, reducing transportation costs and water lost to evaporation. Managed groundwater replenishment means intentionally placing or keeping more groundwater in the aquifer than what would otherwise occur naturally. Managed groundwater replenishment can be achieved directly through a variety of actions, such as:

- Construction of spreading basins or injection wells.
- Managed releases of water down natural channels or man-made canals.
- Intentional flooding of agricultural lands to increase seepage into underlying aquifers.

Managed groundwater replenishment can also occur indirectly through in-lieu recharge, by providing surface water to users who would normally use groundwater, thereby leaving more groundwater in place. Groundwater replenishment can also occur as a secondary benefit of some actions, including deep percolation from applied irrigation water and water placed into unlined conveyance canals.

7. Recharge methods of Aquifers

Artificial recharge methods can be classified into two broad groups (i) Direct methods, and (ii) Indirect methods.

A. Direct methods

1) Surface spreading techniques

The most widely practiced methods of artificial recharge of groundwater employ different techniques of increasing the contact area and resident time of surface-water with the soil so that maximum quantity of water can infiltrate and augment the groundwater storage. Areas with gently sloping land without gullies or ridges are most suited for surface-water spreading techniques.

- *Flooding:* The technique of flooding is very useful in selected areas where a favorable hydro-geological situation exists for recharging the unconfined aquifer by spreading the surplus surface-water from canals / streams over large area for sufficiently long period so that it recharges the groundwater body. This technique can be used for gently sloping land with slope around 1 to 3 percentage points without gullies and ridges.
- *Ditches and Furrows:* In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches and furrows provide maximum water contact area for recharging water from the source stream or canal. This technique requires less soil preparation than the recharge basin technique and is less sensitive to silting.
- *Recharge Basins:* Artificial recharge basins are either excavated or enclosed by dykes or levees. They are commonly built parallel to ephemeral or intermittent stream-channels. The water contact area in this method is quite high which typically ranges from 75 to

90 percentage points of the total recharge area. In this method, efficient use of space is made and the shape of basins can be adjusted to suite the terrain condition and the available space.

- *Run-off Conservation Structures:* In areas receiving low to moderate rainfall, mostly during a single monsoon season, and not having access to water transferred from other areas, the entire effort of water conservation is required to be related to the available in situ precipitation.
- *Gully plugs:* These are the smallest run-off conservation structures built across small gullies and streams rushing down the hill slopes carrying drainage of tiny catchments during rainy season. Usually, the barrier is constructed by using local stones, earth and weathered rock, brushwood, and other such local materials.
- *Contour barriers:* These involve a watershed management practice so as to build up soil moisture storages. This technique is generally adopted in areas receiving low rainfall. In this method, the monsoon run-off is impounded by putting barriers on the sloping ground all along contours of equal elevation. Contour barriers are taken up on lands with moderate slopes without involving terracing. In areas where uncultivated land is available in and around the stream-channel section, and sufficiently high hydraulic conductivity exists for sub-surface percolation, small tanks are created by making stop dams of low elevation across the stream. The tanks can also be located adjacent to the stream by excavation and connecting them to the stream through delivery canals. These tanks are called "percolation tanks" and are thus artificially created surface-water bodies submerging a highly permeable land area so that the surface run-off is made to percolate and recharge the groundwater storage.
- *Stream-channel Modification:* The natural drainage channel can be modified with a view to increase the infiltration by detaining stream flow and increasing the stream-bed area in contact with water. This method can be employed in areas having influent streams (stream-bed above water table) which are mostly located in piedmont regions and areas with deep water table (semi-arid, arid region and valley fill deposits). Stream- channel modification methods are generally applied in alluvial areas.
- *Surface Irrigation:* Surface irrigation aims at increasing agricultural production by providing dependable watering of crops during gaps in monsoon and during non-monsoon period. Wherever adequate drainage is assured, if additional source water becomes available, surface irrigation should be given first priority as it gives a dual benefit of augmenting groundwater resources.

2) Sub-surface techniques

When impervious layers overlie deeper aquifers, the infiltration from surface cannot recharge the sub-surface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface-water source are grouped under sub-surface recharge techniques.

- *Injection Wells:* Injection wells are structures similar to a tube well but with the purpose of augmenting the groundwater storage of a confined aquifer by "pumping in" treated surface-water under pressure. The aquifer to be replenished is generally one that is already over exploited by tube well pumping and the declining trend of water levels in the aquifer has set in. Artificial recharge of aquifers by injection wells is also done in coastal regions to arrest the ingress of seawater and to combat the problems of land subsidence in areas where confined aquifers are heavenly pumped. Due to higher well losses caused by clogging, the injection wells display lower efficiency (40 to 60 percentage points) as compared to a pumping well of similar design in the same situation. The source water and the water in the aquifer should be compatible to avoid any precipitation, causing clogging of well. Injection-cum-pumping wells are more efficient because the well can be cleaned during pumping operation.
- *Gravity-Head Recharge Wells:* In addition to specially designed injection wells, ordinary bore wells and dug wells used for pumping may also be alternatively used as recharge wells, whenever source water becomes available. In certain situations, such wells may also be constructed for effecting recharge by gravity inflow.
- Connector Wells: Connector wells are special type of recharge wells where, due to difference in potentiometer head in different aquifers, water can be made to flow from one aquifer to other without any pumping. The aquifer horizons having higher heads start recharging aquifer having lower heads.
- *Recharge pits:* Recharge pits are structures that overcome the difficulty of artificial recharge of phreatic aquifer from surface-water sources. Recharge pits are excavated of variable dimensions that are sufficiently deep to penetrate less permeable strata. A "canal trench" is a special case of recharge pit dug across a canal bed. An ideal site for canal trench is influent stretch of a stream that shows up as dry patch. One variation of recharge pit is a "contour trench" extending over long distances across the slope and following topographical contour. This measure is more suitable in piedmont regions and in areas with higher surface gradients. As in case of other water spreading methods, the source water used should be as silt free as possible. In case of hard rock terrain, a canal bed section crossing permeable strata of weathered

fractured rock or the canal section coinciding with a prominent lineament or intersection of two lineaments, form ideal sites for canal trench.

- *Recharge Shafts:* In case, poorly permeable strata overlie the water table aquifer located deep below land surface, a shaft is used for causing artificial recharge. A recharge shaft is similar to a recharge pit but much smaller in cross-section.

B. Indirect methods

1) Induced recharge

It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface-water, to induce recharge to the groundwater reservoir. In hard rock areas, the abandoned channels often provide good sites for induced recharge. The greatest advantage of this method is that under favorable hydro-geological situations, the quality of surface-water generally improves due to its path through the aquifer materials before it is discharged from the pumping well.

- *Pumping Wells:* Induced recharge system is installed near perennial streams that are hydraulically connected to an aquifer through the permeable rock material of the stream-channel. The outer edge of a bend in the stream is favorable for location of well site. The chemical quality of surface-water source is one of the most important considerations during induced recharge.
- *Collector Wells:* For obtaining very large water supplies from river-bed, lake-bed deposits or waterlogged areas, collector wells are constructed. The large discharges and lower lift heads make these wells economical even if initial capital cost is higher as compared to tube well. In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal wells may be more appropriate than vertical wells. Collector well with horizontal laterals and infiltration galleries can get more induced recharge from the stream.
- *Infiltration Gallery:* Infiltration galleries are other structures used for tapping groundwater reservoir below river-bed strata. The gallery is a horizontal perforated or porous structure (pipe) with open joints, surrounded by a gravel filter envelope laid in permeable saturated strata having shallow water table and a perennial source of recharge. The galleries are usually laid at depths between 3 to 6 metres to collect water under gravity flow. The galleries can also be constructed across the river-bed if the river-bed is not too wide. The collector well is more sophisticated and expensive but has higher capacities than the infiltration gallery. Hence, choice should be made by the required yield followed by economic aspects.

2) Aquifer modification

These techniques modify the aquifer characteristics to increase its capacity to store and transmit water. With such modifications, the aquifer, at least locally, becomes capable of receiving more natural as well as artificial recharge. Hence, in a sense these techniques are artificial yield augmentation measures rather than artificial recharge measures.

- *Bore Blasting:* These techniques are suited to hard crystalline and consolidated strata. Through hydro-geological investigation, suitable sites are fixed where the aquifer displays limited yield that dwindles or dries in winter or summer months. All the blast holes reach the depth of the aquifer required to be benefited, whether unconfined or confined. All the charges of row or circle are exploded at a time.
- *Hydro-Fracturing:* In many cases, blasting has given indifferent results. Hydro-fracturing is a recent technique that is used to improve secondary porosity in hard rock strata. Hydro-fracturing is a process whereby hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and extend existing fractures. The water under high-pressure break up the fissures cleans away clogging and leads to a better contact with adjacent water bearing strata. The yield of the bore well is improved.

In hydro fracturing, vertical fractures are initiated which inter-connects aquifers at different levels in addition to extension of existing fractures. This leads to better conditions for artificial recharge. The technique may be applied at bore well sites located in hard crystalline rock or other massive consolidated strata including metamorphic and sedimentary formations. Generally, a bore well giving low or poor yield is treated, but the technique can also benefit other wells.

3) Groundwater conservation structures

The water artificially recharged into an aquifer is immediately governed by natural groundwater flow regime. It is necessary to adopt groundwater conservation measures so that the recharged water remains available when needed. Groundwater Dams/ Underground Barriers: A groundwater dam is a sub-surface barrier across stream that retards the natural groundwater flow of the system and stores water below ground surface to meet the demands during the period of greatest need. The main purpose of groundwater dam is to arrest the flow of groundwater out of the sub-basin and increase the storage within the aquifer. The sub-surface barriers need not be only across the canal bed. In some micro watersheds, sub-surface dykes can be put to conserve the groundwater flow in larger area in a valley. Sites have to be located in areas where there is a great scarcity of water during the summer months or there is a need for additional water for irrigation.

Technical possibilities of constructing the dyke and achieving large storage reservoirs with suitable recharge conditions and low seepage losses are the main criteria for sub-surface dyke. It directly benefits up-gradient area and hence care should be taken that a large number of users are not located immediately downstream. Fracture-Sealing Cementation

Technique: In many hard rock areas, the groundwater circulation to deeper levels is governed by shear, fault or fracture plane indicated by lineaments. The boreholes located on such zones prove productive but due to dissipation of the limited storage along preferred flow planes, in case of adverse topographical situation, these become dry by the end of winter or summer. Fracture-sealing cementation is a suitable water conservation measure in such situations. This measure can also be used to prevent ingress of saline or polluted water from a known source. The groundwater flow system at the site should be adequately known to establish the outflow direction and the preferred fracture planes along which the flow occurs under the influence of the natural hydraulic gradient. Under certain hydro-geological conditions, a combination of several surface recharge and sub-surface recharge methods and groundwater conservation techniques, can be used in conjunction for optimal recharge of groundwater.

8. Porous asphalt pavement

Porous asphalt allows for runoff volume and rate control, plus pollutant reductions. Projects use porous asphalt to meet post-construction storm water quantity and quality requirements. The use of porous asphalt can potentially reduce additional expenditures and land consumption for conventional storm water collection, conveyance, and detention infrastructure. Porous asphalt can replace traditional impervious pavement for most pedestrian and vehicular applications. It performs well in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways.

The environmental benefits from porous asphalt allow it to be incorporated into low impact development programs. The appearance of porous asphalt and conventional asphalt is very similar. The surface texture of porous asphalt is slightly rougher, providing more traction to vehicles and pedestrians.

A. Composition of porous asphalt pavement

Traditional pavement surfaces are virtually impermeable and are used in conjunction with ditches and storm drains to channelize precipitation towards storm water management facilities. Permeable pavements provide a different approach. Rather than channelizing precipitation along the surface of the pavement, the water is allowed to infiltrate and flow through the pavement surface where it can be stored and slowly allowed to return into the local groundwater system. Permeable pavements provide runoff reduction and make a significant contribution to on-site trapping, removing and treating storm water pollutants. Permeable pavements are designed to infiltrate storm water, reduce peak flows, filter and clean contaminants in the water stream and promote groundwater recharge. They have become an integral part of low impact design and best management practices for storm water management. In order to be effective, permeable pavements must be designed to provide sufficient structural capacity to accommodate the anticipated vehicle loadings as well as deal with storm water flowing into and out of the permeable pavement.

Permeable pavement systems consist of a surface with joints and/or openings that will freely allow water to infiltrate the system. The openings allow water from storm events to flow freely through the surface into an open-graded base/sub base where it is collected and stored before it leaves the pavement structure. For low-infiltration rate soils, perforated drain pipes are often placed in the sub base or subgrade to drain excess water, thereby functioning as a detention facility that provides treatment for removal of storm water pollutants and allows some infiltration. For sites that do not allow for any infiltration, permeable pavement is designed with an impermeable liner that prevents water from entering the soil subgrade; water is detained, treated, and exits via under drains.

B. Design consideration of porous asphalt pavement

There are three considerations required when determining the thickness of the layers of porous pavements: 1) site considerations to ensure that the site is acceptable; 2) hydrological design to ensure the porous pavement meets the potential storm water runoff demands; and, 3) structural design to ensure that the porous pavement withstands the anticipated traffic loading. Most often, the thickness of the stone recharge bed will be controlled by the water quantity (hydrological design) and soil infiltration rates (site considerations), rather than structural requirements, while the porous asphalt surface layer will be determined by the traffic loads (structural design).

1) Site considerations

The location of porous pavements should be considered early during the design process. Contrary to conventional construction pavement siting, porous pavements perform best on upland soils. Additional site considerations include soil types, depth of bedrock, pavement slope, and additional sources of runoff. General site guidelines include:

- Soil infiltration rates of 0.1 to 10 inches/hour. Do not place over known sinkholes.
- Minimum depth to bedrock or seasonal high water should be greater than 2 feet.
- Frost depth should be considered. The University of New Hampshire recommends the bottom of the stone reservoir be 60% of the frost depth. However, many projects in cold regions have been constructed at lesser depths with no problems from freezing noticed.
- The bottom of the infiltration bed should be flat. For roads it may be necessary to construct berms under the pavement surface to retain water on slopes and install drains/overflows at low points.
- For parking areas, the slope of the porous pavement surface should be less than 5%. For slopes greater than 5% the parking areas should be terraced with berms in between.
- Opportunities to route runoff from nearby impervious areas to infiltration bed. Impervious to pervious areas

should be less than a 5:1 ratio for most conditions or 3:1 for sinkhole-susceptible areas (karst formations).

2) Hydrology design

Hydrological design determines what layer thicknesses are required to sufficiently infiltrate, store, and release the expected inflow of water, which includes both rainfall and excess storm water runoff from any adjacent impervious surfaces. This requires information regarding the layer thicknesses and subgrade permeability along with precipitation intensity levels. Porous pavements are often not designed to store and infiltrate the maximum precipitation at the site. Therefore overflow should be included in the design to prevent stored storm water from reaching the surface layers. This typically will involve perforated pipes in the stone reservoir that are connected to discharge pipe. It is also recommended that an alternate path for storm water to enter the stone reservoir be provided in case the surface should become plugged.

3) Structural design

While limited structural information is available, porous pavements have lasted for more than 20 years. For porous pavements carrying light automobile traffic only, the structural requirements are not significant, and the material thicknesses are determined by the hydrological design and minimum thicknesses required for porous asphalts. For porous asphalt pavements expected to carry truck loads, the structural design procedures should follow standard AASHTO 93 design procedures. Recommended layer coefficients for porous asphalt pavements should be taken.

9. Conclusion

With the study of methods of recharge of aquifers, it can be concluded that,

- Groundwater contamination is extremely difficult, and sometimes impossible, to clean up. Groundwater is one of our most valuable drinking water resources.
- Groundwater contamination occurs when man-made products such as gasoline, oil, road salts and chemicals get into the groundwater and cause it to become unsafe and unfit for human use.
- Recharge is the replenishment of water to a groundwater system from the ground surface. It can occur naturally or artificially.
- An aquifer is a geological formation that contains water and permits significant quantity of water to move through it under ordinary field condition. It is a porous, permeable, water-bearing geological body of rock generally restricted to materials capable of yielding an appreciable amount of water.
- Artificial recharge methods can be classified into two broad groups (i) Direct methods, and (ii) Indirect methods.
- Permeable pavements are designed to infiltrate storm water, reduce peak flows, filter and clean contaminants in the water stream and promote groundwater recharge.

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