Post Equals Pre Is the Key

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ABSTRACT
An alternate approach and philosophy to stormwater management is for the post-development condition to mimic the natural hydrologic functions and water quality of the pre-development conditions. This post equals pre approach will result in better protection of receiving waters than conventional stormwater management. The aims of the study include identifying jurisdictions of where the post equals pre philosophy as been established as policy, identifying the benefits of a post equals pre stormwater management approach, exploring Low Impact Development techniques, innovative stormwater Best Management Practices, and Integrated Water Management as a means to achieving the post equals pre philosophy, and incorporating LID, innovative BMPs, and IWM into a collaborative stormwater management approach. The results of the study have identified jurisdictions where the post equals pre philosophy is policy, the benefits of the approach, that LID, innovative BMPs, and IWM can help achieve the post equals pre approach to stormwater management, and that these measures can be incorporated into a collaborative stormwater management approach. The major conclusion is that methods for implementing the post equals pre philosophy have been identified and jurisdictions should adopt this philosophy as policy to better protect receiving waters.

KEY WORDS
Innovative BMPs, integrated water management, low impact development, post-development volume, pre-development volume, water harvesting

INTRODUCTION
Instead of just mitigating stormwater impacts from new development on receiving waters eliminating those impacts should be the ultimate goal. An alternate approach to stormwater management for a development site, in contrast to traditional end of pipe flood controls and treatment controls, is for the post-development condition to mimic the natural hydrologic functions and water quality of the pre-development conditions. By mimicking the pre-development hydrologic regime the volume of surface water runoff from the developed site more closely matches the pre-development volume of surface water runoff. Maintaining the pre-development volume of surface water runoff leaving a development site is the first step or goal in eliminating impacts from new development on receiving waters. Maintaining the pre-development volume also assists with the second goal in eliminating impacts from new development on receiving waters, which is to maintain pre-development pollutant loads discharging from the development site ensuring pre-development water quality. By maintaining the pre-development volume of surface water runoff, this reduces proportionally the load of pollutants being discharged by the site and reduces the volume of water to be treated by on site water quality treatment controls. The purpose of this paper is to explore where the post equals pre philosophy has been implemented as policy, identify the benefits of

the approach, identify what are the measures to practically implement the approach, and how these measures can be implemented in collaborative manner.

METHODS

The methodology for the study included a legislative review of stormwater management policies in different jurisdictions primarily in the United States to identify those jurisdictions that have embraced the post equals pre approach to stormwater management and have implemented it as policy or regulation. The legislative history of these policies and regulations and other research was performed to identify what factors influenced the development of these policies. The tools that can be used to implement the post equals pre philosophy were then explored. Research focused on Low Impact Development and identifying what LID techniques could help to achieve the post equals pre philosophy. Innovative BMPs where also researched to identify those BMPs that helped to mimic the hydrologic and pollutant load pre-development conditions. Integrated Water Management principles were researched in the context of how stormwater fits into the IWM model. As apart of the IWM research water harvesting techniques were researched and jurisdictions where water harvesting was being implemented were identified. A collaborative stormwater management approach was then developed that incorporated how LID, innovative BMPs, and IWM could be used to achieve the post equals pre philosophy.

RESULTS AND DISCUSSION

Adopted Post Equals Pre Policies

The post equals pre philosophy has been adopted as policy in a variety of jurisdictions within the United States and abroad. These jurisdictions and their specific policies are identified below.

Federal. The post equals pre stormwater management approach is found in the Energy and Independence Security Act of 2007. Section 438 that covers Storm Water Runoff Requirements for Federal Development Projects states "The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the pre-development hydrology of the property with regard to the temperature, rate, volume, and duration of flow (U.S. Congress, 2007)." The Federal Government in the United States often uses regulations for Federal facilities as a catalyst to change behavior throughout the country. Section 438 is attempting to do this by requiring federal facilities to maintain or restore pre-development hydrology for any development or redevelopment. The significance of this provision is that the Federal Government of the United States recognizes the benefits of the post equals pre philosophy and has made it law to institute this philosophy for all development and redevelopment of federal facilities.

State of Delaware. The State of Delaware has adopted regulation 10.3.1 in its Sediment and Stormwater Regulations that embodies the post equals pre philosophy as it states "It is the overall goal of the Department to utilize stormwater management as a means to minimize water quantity and water quality impacts due to land disturbing activities and to mimic pre-development hydrology, to the maximum extent practicable, in regards to the rate, volume and duration of flow. These regulations will provide general design requirements that must be adhered to in the absence of Designated Watershed or Subwatershed specific criteria (Delaware, 2006)."

Pasco County, Florida. Pasco County has adopted an ordinance that embraces the post equals pre philosophy as it states "Runoff volume shall be limited to pre-development conditions such that there shall be no increase in the volume of runoff resulting from development activity for a 100-year return frequency, 24 hour duration storm event (Pasco County, 1998)."

City of Redwood, California. The City of Redwood California is also embracing the post equals pre philosophy by identifying its goal to drainage design as the following "The goal of drainage design is to maintain post-development stormwater runoff to pre-development runoff conditions (City of Redwood, 2004)." The City has also required the following for runoff control "Runoff Control - To the extent practicable, maintain post-development peak runoff rate and average volume of runoff at levels that are similar to pre-development levels. The developer must design the proposed project accordingly (City of Redwood, 2004)."

U.S. Green Building Council. The U.S. Green Building Council has identified in its New Construction Reference Guide that Credit 6.1 Stormwater Design Quantity Control option 1 that the credit can be achieved by the following, "Implement a stormwater management plan that prevents the post-development peak discharge rate and quantity from exceeding the pre-development peal discharge rate and quantity for the one- and two-year, 24-hour design storms (USGBC, 2006)." The USGBC New Construction Reference Guide is designed to promote the most cutting edge environmentally friendly policies in the area of new development, which underscores the importance the USGBC has put on maintaining the pre-development hydrology of a development site.

Australia. Australia has also embraced the post equals pre philosophy through a goal for new development as the following, "A goal for new development is to ensure that the post-development peak discharge rate, volume, timing and pollutant load does not exceed pre-development levels (Environment Australia, 2002)."

It is clear that at every level of government in the United States, at the leading organization of sustainable environmental design in the U.S., and in at least one other country the post equals pre philosophy is policy.

Post Equals Pre Benefits

The range of benefits of implementing a post equals pre approach to stormwater management include environmental factors, flood control safety concerns benefits to human health and recreation, and economic benefits. Environmental factors of the post equals pre philosophy include benefits to receiving waters in the form of improved water quality and prevention of erosion in natural streams and rivers. By implementing this approach and mimicking the natural pollutant loads discharging from a development site this will eventually eliminate the impacts of excessive pollutants in receiving waters. Implementing this approach and maintaining the pre-development volume of surface water discharged from the site will reduce downstream river and stream bank erosion. Hydrologic conditions of concern include those associated with erosion of downstream receiving waters from increased volumes of water, beyond natural conditions, being discharged from development sites during major storm events. This erosion impacts the receiving water quality by increasing the suspended solids, affecting benthic organisms by increased sediment deposits, changing river morphology, and causing flood control hazards. Implementing the post equals pre philosophy would help to eliminate these impacts of increased runoff volumes.

Flood control safety benefits of the post equals pre philosophy are from a development condition that mimics the natural hydrology including the reduction of flooding issues due to reliance on traditional end of pipe flood control structures provided the development is not placed in a flood plain. Flooding occurs in part due to large amounts of connected impervious surfaces, associated with traditional developments, preventing water from infiltrating into the ground or being absorbed by vegetation, which occurs in a natural hydrologic regime. As the volume of water increases with the intensity of storm events, end of pipe flood control structures may become overwhelmed and flooding may occur. Flooding is less likely to occur if development mimics the natural hydrology of a site. By maintaining the pre-development volume of runoff for a site this reduces the need for large flood control structures down stream. Flood control structures can also cause a public safety hazard by preventing sediment transport downstream. In many cases sediment deposits form barrier islands, sand bars, and wetlands that serve as a natural barriers to large storm events and so if the sediment deposits are reduced due flood control structures the natural barriers to storm events may eventually be eliminated. A study of the coastal barrier islands and wetlands in Louisiana identified that the construction of flood control structures along the Mississippi designed to accommodate development is causing the erosion of barrier islands and coastal wetlands (USGS, 2004).

The post equals pre philosophy also provides benefits to human health. Receiving waters have a variety of beneficial uses some of which are directly related to human health and recreation. One beneficial use directly related to human health is drinking water supply. As development sites discharge increasing amounts of pollutants, the affects to drinking water supplies in downstream receiving waters can be impacted. In urban areas in the world approximately 60% of the population rely on surface waters as their source of water (UNHSP, 2004). In the United States approximately 74% of freshwater comes from surface water sources (USGS, 2005). These studies underscore the importance of maintaining the quality of our surface waters. Implementing the post equals pre philosophy and mimicking the natural pollutant loads discharging from a development site will help to eliminate the impacts to drinking water supplies in downstream receiving waters. Another beneficial use directly related to human health is fishing. Pollutant loads discharging from development sites cause impacts to aquatic species which then have the potential to impact humans consuming those species. The post equals pre approach will help to eliminate excessive pollutants beyond natural inputs.

As more and more receiving waters are used for recreational activities this exposes more people to the pollutants contained in those receiving waters. Streams, rivers, lakes, and the ocean are all used for recreational activities. Many of the pollutants contained in surface water runoff from development sites can be hazardous to human health through water contact. Some of these pollutants include polyaromatic hydrocarbons that are known human carcinogens, fecal coliform bacteria can cause numerous illnesses including ear and eye discharges, skin rashes, and gastrointestinal problems, and excess levels of nitrate can cause methemoglobinemia and an increase miscarriage risk (Riverlink, 2008). Many recreational activities including boating, surfing, kayaking, and river rafting are affected by excessive sediment transport due to erosion from increased volumes of runoff from development sites or by flood control structures limiting access or preventing sediment transport. The post equals pre approach will help to eliminate impacts to recreation by reducing pollutants and the volume of runoff causing erosion and the need for flood control structures.

The economic benefits of the post equals pre philosophy include cost benefits to the developer and external economic benefits to the community at large. The developer can benefit from the fact that the cost of traditional end of pipe flood control and water quality treatment controls far exceeds the tools that can be used in the post equals pre stormwater management approach. Low Impact Development has been shown to be up to 70% cheaper than conventional stormwater treatment controls (Blue Land, Water and Infrastructure, 1999). The use IWM and water harvesting can be cost effective by saving the occupiers of development on life cycle water costs. There are many off site economic benefits by implementing the post equals pre philosophy including reduction of the number of flood control structures, maintaining natural habitat and improved aesthetics, which increases property values and increased recreational activities, reduced water supply needs, infrastructure and cost of water, and reduction in funds expended on restoring receiving waters. As a result of improved receiving water quality in some areas tourism will increase which will bring more economic benefit to a region.

Low Impact Development

Low Impact Development (LID) is a different approach to conventional stormwater management that can help to implement the post equals pre philosophy. The LID approach combines hydrologically functional site design and pollution prevention measures to offset the impacts of development on hydrology and water quality (PGC, 1999). The objective of an LID approach is to mimic the pre-development site hydrology by implementing site-design techniques that function similar to natural processes. By using LID techniques for development sites natural watershed hydrologic functions are maintained which results in less impacts to receiving waters from increased volumes and pollutants. LID techniques are also cost effective in many ways including their functionality as they can serve as landscape areas and so be multipurpose, they have lower capital and life time costs than conventional stormwater treatment controls, many of the LID techniques can be designed as part of a development's open space (Lid-stormwater.net, 2007). LID incorporates site planning, hydrologic analysis, and integrated management practices into an overall stormwater approach.

LID Site Planning. The goal of LID site planning is to allow for full development of a site while maintaining the site hydrologic functions (PGC, 1999). LID incorporates five concepts into the site planning process including using hydrology as an integrating framework through preservation of critical hydrologic functions, micromanagement of stormwater by reducing the size of area being managed thus reducing the size of control practices, controlling stormwater at the source, using simplistic non-structural methods, and creating a multifunctional landscape and infrastructure where every urban landscape or infrastructure feature including roofs, streets, parking, sidewalks, green space and landscape can serve as stormwater treatment and other functions (PGC, 1999). Some specific site planning techniques that reduce the post development volume and can help achieve the post equals pre approach include:

- Limit the use of sidewalks
- Reduce road length and width
- Reduce driveway length and width
- Conserve natural resource areas
- Minimize disturbance
- Preserve infiltratable soils
- Preserve natural depression areas

- Use transit zones
- Use vegetated swales
- Preserve vegetation

(PGC, 1999)

LID Hydrologic Analysis. Hydrologic analysis is the tool used to ensure site plans and site designs achieve preservation or restoration of the pre-development hydrologic functions. The preservation of the pre-development hydrology can be achieved through an analysis of runoff volume, peak runoff rates, storm frequency and size, and water quality management (PGC, 1999). LID is designed to provide water quality treatment for the first half-inch of runoff, from impervious areas by using distributed control and retention throughout the site, however the volume of runoff treated usually is in excess of the first half-inch of runoff (PGC, 1999). LID provides a variety of hydrologic modification tools to meet the goal of maintaining the pre-development hydrologic regime. These tools include (PGC, 1999):

- Reduce/minimize imperviousness
- Disconnect unavoidable impervious surfaces
- Preserve and protect environmentally sensitive features
- Maintain the pre-development time of concentration
- Mitigate for impervious surfaces with Integrated Management Practices
- Locate the impervious areas on less pervious soil types

LID Integrated Management Practices. LID Integrated Management Practices are distributed management techniques that assist in meeting the pre-development hydrologic regime and provide treatment for water quality. IMPs are designed for on site implementation, which integrates the site with the natural environment and eliminates the need for conventional end of pipe treatment controls that occupy large areas of land (PGC, 1999). Examples of LID IMPs are provided below:

- Bioretention – Bioretention functions as a soil and plant-based filtration device that removes pollutants through physical, biological, and chemical treatment processes. They can exist as in-ground devices or as infiltration or flow-through planter boxes.
- Filter Strips - A filter strip is a grassy slope located adjacent and parallel to an impervious area such as a parking lot, driveway or roadway.
- Vegetated Buffers – Vegetated buffers are natural or man made strips of vegetation that provide a buffer to protect sensitive areas such as waterbodies, wetlands, or other ecologically sensitive areas.
- Grassed Swales – A grassed swale is an open, gently sloped, and vegetated channel designed to convey stormwater and provides treatment through infiltration and flow through vegetation.
- Rain Barrels – Rain barrels capture rooftop runoff and store it for reuse on the site providing removal of roof top runoff volume and pollutants.
- Cisterns – Cisterns capture rooftop runoff that provide retention and storage in storage tanks, sometimes underground, for reuse.
- Infiltration Trenches – Infiltration trenches are excavated trenches that are then filled with filter fabric and rock to allow infiltration in to the ground.
- Green Roofs - Green roofs are multi-beneficial structural components that help to mitigate the effects of urbanization on water quality by filtering, absorbing,

detaining and evapotranspirating rainfall. They are constructed of a lightweight soil media, underlain by a drainage layer, and a high quality impermeable membrane that protects the building structure. The soil is planted with a specialized mix of plants that can thrive in the harsh, dry, high temperature conditions on the roof and tolerate short periods of inundation from storm events.

The LID approach is effective in realizing the post equals pre philosophy. Figure 1 below shows the effectiveness of LID concepts in maintaining pre-development hydrologic regime. The hydrograph of the LID Concepts more closely mimics the hydrograph of the pre-development conditions.

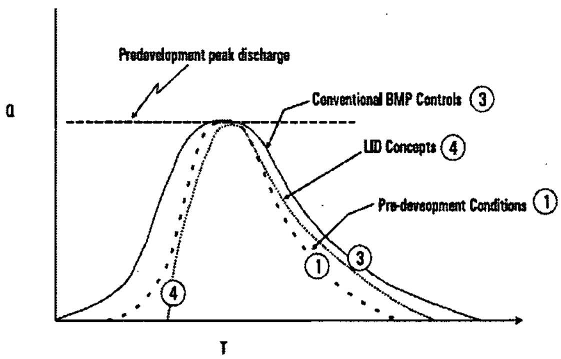

Figure 1. Comparison of LID and Conventional Controls Hydrologic Response to Pre-development Conditions (PGC, 1999).

Innovative Best Management Practices

There are many new emerging and innovative BMPs that can help to achieve the post equals pre philosophy. A variety of innovative BMPs reduce pollutant loads and also reduce volume of surface water runoff from a development, which can be implemented and integrated as part of site design. The innovative BMPs that have been identified to be effective at reducing the volume of stormwater runoff and pollutants include porous pavement, underground detention/infiltration, and the Filterra device.

Porous Pavement. Permeable pavement materials include porous concrete, porous asphalt, and permeable pavers. These pavements provide a stable, functional surface like traditional paving systems, but also allow water to percolate through the material and infiltrate into the ground. This allows for reduction in impervious surface areas at a project site and helps to maintain the pre-development hydrology. Porous concrete is composed of course aggregates, hydraulic cement and other cementitious materials, admixtures, and water. Porous concrete can be highly permeable and can retain significant permeability after prolonged use and soil clogging if proper maintenance of the surface is performed. Porous asphalt is comprised of an open-graded asphalt concrete layer over an open-graded aggregate base, over the sub grade. The difference between porous asphalt and traditional asphalt is that porous asphalt contains very little fine aggregate. Without the fine aggregates to fill the voids in the material, porous asphalt has a void content of about 15%, making it very permeable. Permeable pavers are individual units that are set in a pattern on a prepared base. The units provide the structural integrity for the surface, but are impervious themselves. The spaces between and within the units create impervious areas for infiltration. Open-celled permeable pavers allow for infiltration through precast voids.

Underground Detention/Infiltration. Many site constraints relate to space for placement of stormwater controls. Underground detention/infiltration device offer an innovative solution that saves space in a site layout and helps to maintain the pre-development hydrologic regime. Underground detention/infiltration devices are proprietary BMPs with performances and specifications that vary greatly between different manufacturers. The devices are constructed from high quality PVC plastic, corrugated metal pipe, or concrete. These systems can be configured to have open inverts so that water can infiltrate into the ground. The infiltration configuration systems assist in maintaining the pre-development volume of runoff and pollutants from the site by infiltration into the ground. The closed invert systems detain runoff that then could be pumped for use on the site, which also helps maintain the pre-development volume of runoff and pollutants.

Filterra. Filterra is a bioretention type treatment device that is effective at removing pollutants and can be configured to reduce the volume of stormwater from a development site. Filterra is a bioretention device and so removes pollutants though a variety of physical, chemical, and biological processes. Filterra was co-developed by Larry Coffman, who is the developer of the LID stormwater approach. The system consists of a concrete container, a 3 inch mulch layer, 1.5 to 3.5 feet of a unique soil filter media, an observation / cleanout pipe, an under-drain system and an appropriate type of plant i.e., flowers, grasses, shrub, or tree (Filterra, 2008). Stormwater runoff drains directly from impervious surfaces through an inlet structure in the concrete box and flows through the mulch, plant, and soil filter media. The Filterra device can be configured to have storage beneath the beneath the filter box for either infiltration or detention. With the infiltration configuration the Filterra device assists in maintaining the pre-development volume of runoff and pollutants from the site by infiltration into the ground. With the detention configuration water could be pumped for use on the site, which also helps maintain the pre-development volume of runoff and pollutants.

Integrated Water Management

Integrated Water Management (IWM) offers significant opportunities for reducing the volume of surface water runoff from a development to pre-development conditions. As the demand for water continues to increase on a global scale innovative solutions to supply this resource are needed to meet the demand. The use of surface water runoff from development as water supply is one of the solutions that can help meet that demand. IWM has initially focused on the use of wastewater for reuse opportunities, however the use of surface water runoff as a water supply resource offers many advantages. Surface water runoff from development sites should be recognized as a significant water resource. Some of the advantages of using runoff from a development sites as a water resource include infrastructure, cost, and ground water recharge. Use of development site runoff as a resource can significantly reduce the infrastructure needed for water supply. As populations increase water supply infrastructure will need to keep pace. If stormwater runoff was used onsite for certain non-potable activities it would greatly reduce the need to update and build new water infrastructure to keep up with population growth. In Australia research has shown by using stormwater as a resource by implementing rainwater tanks to supply domestic uses the need to construct new dams in the Sydney, Lower Hunter and Central Coast regions of NSW would be deferred between 38-100 years (EcoSmart, 2008).

Cost is another benefit for using stormwater as a resource. As populations increase and the demand for water increases the cost of water will rise as well which means a higher cost for water supply in developments. By implementing measures to capture stormwater onsite there will be significant reductions of the water needed from centralized water supply and thus reduce costs to the development. Groundwater recharge will also benefit from using stormwater as a resource. Many of the measures that can be implemented to achieve the post equals pre philosophy infiltrate water into the ground. Infiltrating groundwater recharges aquifers, which allows for greater water supply on a regional basis. By implementing a concept of using stormwater as a resource at development sites, measures can be put in place to retain stormwater for future use, which assists in maintaining the pre-development runoff volumes and pollutant loads.

Using stormwater as a resource is also known as water harvesting and has been implemented with success in many places. The City of Tucson, Arizona passed an ordinance on October 18, 2005 supporting water harvesting and approving a water harvesting guidance manual. The Tucson manual identifies many of the water harvesting techniques that can be used including the following:

- Microbasins
- Swales
- French Drains
- Gabions
- Water Tanks
- Mulch

  (City of Tucson, 2005)

Water harvesting programs are starting to gain favor especially when cost savings are identified. Water harvesting is policy in Australia where it is mandatory for any remodeling or new building in most states in Australia (HarvestH2O, 2008). Australia also offers water harvesting tank rebates that start from NSW $100, about $88 in US dollars, for a 2,000 liter (528 gallons) tank and NSW $500, about $442 US dollars, rebates for connection of a rainwater tank to a clothes washing machine and toilets (HarvestH2O, 2008).

Incorporating water harvesting or using stormwater as resource into IWM has many advantages on the local and regional level and can benefit a specific development site in many of the aforementioned ways. Using stormwater as a resource in augmenting IWM can help a specific development site realize the post equals pre philosophy.

Collaborative Stormwater Management Approach

To achieve the post equals pre philosophy LID, innovative BMPs, and IWM using surface water runoff as a resource can all be incorporated into a collaborative stormwater approach. To achieve this approach in a development coordination and collaboration of planners, architects and engineers must happen early in the project development process. These different disciplines must be brought together and collaborate early in the project process to achieve the post equals pre philosophy. The development of a site plan is an iterative process where LID strategies, innovative BMPs, and water harvesting should be considered and the appropriate measures incorporated. The iterative process will require using the site planning techniques of LID and water harvesting to be identified in the first step. To ensure the post-development hydrology mimics the pre-development hydrology the LID hydrologic calculations must be completed after the development of a preliminary site plan. The results of this analysis will identify if LID IMPs, innovative BMPs or additional water harvesting techniques are needed. The final site plan should then incorporate those LID IMPs, innovative BMPs, and water harvesting techniques to ensure that the pre-development hydrologic regime is maintained.

CONCLUSION

The post equals pre approach to stormwater management should be implemented as standard policy to ensure the health of our receiving waters as:

- The approach is policy in jurisdictions in the United States and abroad
- The approach will help eliminate impacts to receiving waters and has many other benefits
- The tools of LID, innovative BMPs, and IWM have been identified to implement this approach.

Through implementation of the post equals pre approach watershed hydrologic regimes will eventually return to more of a natural condition, which will result in the receiving waters returning to a natural condition. This philosophy improves quality of receiving waters, improves flood control safety, reduces water supply and infrastructure needs, improves human health and recreation, and has many economic benefits. As population increases and development continues there is an opportunity to shape what development and the built environment looks like and minimize its impact on the natural environment. The post equals pre philosophy helps to shape the vision of development in a manner that benefits our streams, rivers, lakes and ultimately the world's oceans.

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