Background

ICPR began as a 1D hydrologic and hydraulic (H&H) model more than 30 years ago with a focus on modeling hydraulically interconnected and interdependent pond systems. Hydrodynamic channel and pipe flow were added in the late 1980s. ICPR was the first proprietary H&H model to be formally accepted by FEMA nationally (1995) for use on Flood Insurance Studies. In 2008, a quasi-2D groundwater module was added (PercPack™) which was our first foray into integrated surface water–groundwater modeling.

Our latest generation of ICPR, released in 2014, includes fully integrated 2D surface water and groundwater flow with an emphasis on interactions between surficial aquifer systems and surface water bodies.

- Traditional 1D H&H
- 2D Overland Flow
- 2D Groundwater Flow
- Single Event Simulation
- Continuous Simulation
- Georeferenced Graphic System
- All Modules Fully Integrated

The combination of integrated surface water–groundwater flow and continuous simulation opens the door to many complex water resources applications and issues such as wetland hydro-period assessments, wetland restoration, impacts of sea level rise on groundwater tables, consumptive water use, stormwater reuse, water sustainability, irrigation demands, and construction dewatering.

Flexible Mesh

The 2D computational framework for ICPR is based on a flexible unstructured triangular mesh. This approach allows the mesh to shrink where detail is needed and to grow in less critical areas. The result can be orders of magnitude fewer computational cells than a square cell mesh without loss of detail in critical areas. And, fewer cells mean less computational effort, faster run times, and smaller output files.

The 1D H&H module of ICPR is fully integrated with the 2D overland flow module. Both 1D and 2D equations are solved simultaneously eliminating awkward numerical handoffs between modules. Storm inlets and underground pipe systems are easily incorporated into the model.

Models from Maps

Although it is possible to work in schematic mode for 1D projects, ICPR’s full power is realized through its georeferenced graphic system. Models are constructed and parameterized directly from various types of maps.
Computational meshes are automatically generated from graphical elements that: (1) characterize the terrain; (2) interface with 1D components; and, (3) establish boundary conditions. The mesh is then intersected with surfaces (e.g., terrain) and thematic polygon map layers.

The thematic polygon maps further refine the mesh into subsets of soil zones, impervious zones, roughness zones, and rainfall zones among others.

1D Surface Flow

ICPR uses a link – node concept in its 1D module. Nodes are placed at strategic locations in the drainage network.

Elevations are calculated at nodes based on inflows, outflows and storage characteristics. Water is moved from node to node via links such as pipes, channels, weirs, pumps, and bridges among others. The full St. Venant equations are used for channel and pipe flow. Energy and diffusive wave options are also available.

Stormwater runoff can be calculated using traditional unit hydrographs if desired, and delivered to any node in the model. Several options are available for infiltration losses and rainfall excess computations including the curve number method, the Green-Ampt method, a vertically layered kinematic method and a vertically layered dynamic method based on Richards equation.

ICPR includes a number of tools to help expedite 1D model construction. These tools extract data from map and surface layers. For example, a breakdown of soil and land cover combinations for each catchment area can be automated inside
ICPR. Channel cross sections can be extracted from a ground surface DEM, as well as storage characteristics for lakes, detention ponds, and wetland depressions.

Water surface profiles can be animated along any user defined link path.

**2D Overland Flow**

**Computational Methods**

ICPR uses the finite volume method for 2D overland flow computations. This technique is based on a double mesh where momentum equations are lumped along triangle edges and the mass balance equations are lumped into irregular shaped polygons (“the honeycomb”)

formed around the triangle vertices. Water surface elevations are calculated at the triangle vertices and water is moved from polygon to polygon along the triangle edges.

Mesh generation is fully automated, including parameterization. For example, the honeycomb mesh is intersected with land use zones and soil zones to form a set of sub-polygons. Direct rainfall is applied to and infiltration losses calculated for each sub-polygon. Rainfall excess is summed by honeycomb and delivered to its respective triangle vertices.
The triangular mesh and corresponding honeycomb are flexible and unstructured, allowing the mesh to grow and shrink as needed to capture critical areas in the drainage system.

**Graphical Elements**

A variety of graphical elements are included in ICPR that allow you to customize and finesse mesh construction. The graphical elements are categorized as follows:

- **Terrain Characterization**
- **Interface with 1D Elements**
- **Establish Boundary Conditions**

For example, breaklines are used to define local ridges and valleys. A triangle edge is guaranteed along the breakline, and as mentioned, flow occurs along triangle edges. Strategic placement of a breakline can prevent artificial blockage along flow paths or tunneling through a ridge.

There are a total of 18 2D overland flow graphical elements. These can be drawn manually inside ICPR, or imported from shapefiles.

**Animations**

The typical way to review results for 2D modeling is with animations. ICPR includes a wide variety of possible animations for 2D overland flow including flow and velocity vectors, depth of flow, maximum depth of flow and water surface elevations among others.

Animations can be viewed in “play mode” or you can manually step through them.
You can also go directly to a specific point in time. Most animations can be paused and then exported by simply right-clicking on the animation view.

## 2D Groundwater

### Computational Methods

The 2D groundwater module in ICPR is based on the finite element method with a 6-point quadratic triangular element.

- Heads Calculated at Nodes
- Saturated Horizontal Flow
- Seepage at Ground Surface
- Leakage Through Confining Layer

The focus of the groundwater module is the surficial aquifer and its interaction with surface water bodies. It includes seepage between the ground surface and the surficial aquifer as well as vertical leakage through a confining layer. Seepage and leakage are bi-directional. Spatiotemporal boundary conditions can be applied below the confining layer.

Like the surface, a honeycomb is formed around the vertices of the triangular computational mesh. But unlike the surface, the honeycomb is also formed around mid-nodes. The surface and groundwater honeycombs are intersected with one another and with soil zones, impervious zones and rainfall zones. The result is a set of sub-polygons, each having a surface ID, a groundwater ID and soil, land cover and rainfall station attributes.

Rainfall excess for any sub-polygon is delivered to the corresponding surface node and recharge is delivered to its associated groundwater node.

Surface and groundwater meshes do not have to be aligned.

### Graphical Elements

Various groundwater graphical elements are used to aid in mesh construction, similar to overland flow.

Irrigation wells and drains (tile drain or roadway underdrain) can be included in your project. An exclusion graphic element can be used to model a fully penetrating retaining wall. Boundary conditions can be specified at a
point, along a line, or over an area (polygon). Both stage and flow boundary conditions are possible.

Results and Animations

Like overland flow, there is a wide variety of reports and animations available for analyzing the groundwater results.

Here is an example of a proposed commercial site with 2 retention ponds that rely on percolation for storage recovery. There is a river south and east of the site and groundwater flow is toward the river. Fluctuating water levels in the river automatically become known head conditions for the groundwater model.

Groundwater elevations at hour 120 are shown above. Cross section A–A’ depicts ground elevations, the initial water table and the water table at 120 hours, 4 days after the rain stopped.

Aggregate seepage amounts between the river and the adjacent water table are shown below. The river rises faster and higher than the adjacent water table. Consequently, a portion of the river flow seeps from and into the water table. Later, as the river subsides, there is seepage from the water table into the river.

Section B–B’, through the two ponds, indicates that they have not fully recovered after 120 hours.
Demonstration Project

Levee Breach, Village of Wellington
Palm Beach County, Florida

The Village of Wellington study area is approximately 29.5 square miles in size. The area is surrounded by a levee and primary drainage is through a system of canals and pump stations. The western and southern levee separates Wellington from Water Conservation Area 1 (“WCA 1”), a large headwater wetland system to the Everglades.

Village of Wellington
(29.5 sq. mi.)

The purpose of this modeling effort is to demonstrate the integrated surface water – groundwater capabilities of ICPR for a levee breach application. It is intended for demonstration purposes only and results should not be used for planning or design purposes.

Two “sunny day” breach paths were included in this model. Breach path “A” includes failure of the outer levee followed by failure of an inner levee at a pump station. Breach path “B” is in the same general location, but a little farther north. In both cases, the outer levee failure completed in 2 hours. Repairs began 24 hours after the breach initiated and were completed 5 days later.

The surface model included both 1D and 2D components. The primary channel system, all structures and most of the ponds and depressions were modeled with 1D components. Everything else was modeled with 2D components. The extent of the 1D channel system was from top of bank to top of bank.
2D groundwater flow was included in the model. The soils are very permeable and significant volumes of water are expected to move horizontally from the canals to the water table. Also, water will move vertically through the soil column to the water table as the flood wave propagates overland. The seepage will reverse as the canals are pumped down.

The maximum extents of surface flooding for both breach paths are shown below. Breach path “A” results in more extensive flooding than breach path “B”. There are steeper gradients between WCA 1 and the canal system with breach path “A”, causing a higher volume of water to pass through the system.

The propagation of the groundwater mound for breach path “A” at hours 24, 48 and 120 are shown below. Notice that as the water moves through the canal system, the groundwater mound builds perpendicularly outward from the canals.

Approximately 20% of the total inflow volume for the breach path “A” scenario is lost to horizontal seepage from the canals.