gathering place.

The evaluation of the site from a hydraulic standpoint found that this site could have a tributary area of close to 6 acres that could be managed by any stormwater facility on site. In addition, the area around the parcel suffered from flooding that could be up to a foot deep during rain events. The local flooding caused property damage due to poor drainage patterns and a lack of stormwater infrastructure. Figures 1 and 2 show the flooding that occurred along the northern edge of the proposed site, including the structures that were impacted by the poor existing drainage.

The parcel was evaluated and it was determined that the flooding could be alleviated and the water quality volume could be captured using the available land on the nearby parcel, the local topography and the invert depth of the existing connection back into the storm system. Given the depth of bioretention needed to provide significant storage, a critical component was verifying that the underdrain and filtered stormwater could be discharged back into the storm system. While the local storm sewer system was not found to be deep enough, a 72-inch storm sewer located a block to the west of the site was found to provide sufficient depth to allow for the required bioretention size and depth and still allow a positive discharge back into the storm sewer.

Design Development

The site evaluation allowed us to identify the required size of the stormwater management facilities for the site and recommended the use of two bioretention cells on site that were connected by underdrain to a single discharge point. Given the location of the existing drainage around the property, the use of 2 cells at either end of the parcel enabled each cell to be as shallow as possible by minimizing the inlet length for each cell. Based on the vision of the City's Blueprint program, the site needed to have some neighborhood amenities that would provide a positive impact on the neighborhood.

Some initial conversations were held with a number of local stakeholders, including the Parsons Avenue Merchant Association as well as the neighborhood liaison for the Reeb-Hosack neighborhood. The City's Office of Sustainability also provided some initial thoughts on potential features to be included on the project site. Through these discussions, the following amenities were identified for inclusion in the project:

- **Playground:** Across the street, the former Reeb Elementary School was being repurposed as a community center and as a result of construction, the playground at the school was being demolished. Adding a playground on the new site would help to replace the previous one at the school
- **Pervious Basketball Court:** Similar to the playground, the basketball court at the school site was demolished as part of the community center development. This would serve as a replacement for the basketball courts that were lost as part of the new community center.
- **Shelter Area:** An area was desired for some picnic tables and seating that could be used as a gathering area for the community
- **Walking Path:** One of the other developments in the area was a senior citizens development called Parsons Village. One of the suggestions was to provide a walking path for the site that could be used as exercise for the adjacent senior complex.

A number of layouts were considered given the above features as well as the 2 bioretention cells. Based on feedback from City staff, an initial site layout was chosen that included all of the amenities as well as sufficient space for the stormwater controls. Figure 3 shows the conceptual layout that was developed that incorporated all of the associated amenities that were to be included in the South Side Settlement Heritage Park.

Figure 3. South Side Settlement Heritage Park Conceptual Layout

Once the initial layout was developed, it was identified that a number of different City departments would need to be involved in the approval process to realize the goals of the project. While the Division of Sewerage and Drainage was managing and funding the project, due to the urban nature of the project and the City's departmental structure, several other departments had to be consulted and grant approval before the project could be constructed. Each department offered specific design guidance that provided a benefit to the project and that needed to be incorporated prior to final approvals.

Recreation and Parks: The Department of Sewerage and Drainage specializes in the design and construction of sanitary and storm drainage but had not developed any recreational parks in its history. Close coordination with the Recreation and Parks department was needed to ensure that this park was designed appropriately and also would be similar to other city-owned parks for consistency. This department was instrumental in helping to identify the following needs for the park and provide feedback to inform the design:

- **Use of shelter picnic tables but not a single shelter:** a single shelter can create issues while multiple separate tables are easier to utilize in a park
- **Safety fences for the playground and basketball court:** given the presence in an urban area, providing fencing around the court and the playground would be necessary to prevent children from entering the surrounding streets
- **Inclusion of a smaller basketball court to prevent use of a full court game:** given the target for this playground and court were smaller children, a half-court basketball hoop was thought to be a better option.
- **Specific playground recommendations**: including recommended equipment and base material being padding as opposed to mulch

- **Specific bench and trash can recommendations for use in the park:** these included benches and trash cans that were used in other city parks

Department of Public Service: The City's Department of Public Service manages the City's roadways. To achieve the required drainage for the park's quantity and quality control, our team recommended regrading of surrounding roadways to improve local flooding condition. Working with DPS enabled the plans to be in compliance with the City's policies and ensure approval.

Division of Water: To install the new storm sewer required relocation of some Division of Water assets including a hydrant and some small sections of water mains; our team worked with this division to ensure that their standards were met when designing the improvements around potable water infrastructure.

Similarly, there were a number of community organizations that were included in the design process and several public meetings as well as individual meetings that were conducted to ensure that the project was acceptable to the local community.

Public meetings were held with the Reeb-Hosack Civic Association, which is the local neighborhood organization, as well as the South Side Area Commission, which is the larger board that helps to oversee development in the South Side portion of Columbus. In public meetings with both groups, feedback was positive and residents provided support given the amenities that were being included within the design. Our team also met with groups from the Reeb Community Center and the Parsons Avenue Merchant Association as part of the detailed design process. Some examples of items that were discussed and reviewed as part of the design include:

- **A 7.5' basketball hoop:** In addition to a 10' basketball hoop, the inclusion of a 7.5' basketball hoop for the local Big Brothers/Big Sisters chapter at the nearby Reeb Community Center, which has a number of 5/6 year old programs that would require a shorter hoop for children
- **No parking:** there is available street parking in the area and this was envisioned as a neighborhood park, so inviting additional traffic to the park was not recommended

Overall, while the overall concept of the project was developed within the City team, the feedback provided by additional City departments and public groups was instrumental in ensuring that the details of the project aligned with the neighborhood and the City standards to ensure the project was a success. The construction of the park was completed in spring 2016. Figures 4 and 5 show the park following construction.

Post Construction Inspection and Maintenance

The park has been in use for the past 3 years. Following the construction of the park, the City began evaluating the health and effectiveness of the bioretention cells as well as the inspection and maintenance requirements for both the park components as well as the bioretention. Another significant aspect of ensuring that the Blueprint program is successful is having a robust inspection and maintenance program that ensures the constructed bioretention is still performing at the designed level and that ratepayers are satisfied with the aesthetic appearance and overall condition of the stormwater facilities.

Monthly inspections track the health of the plants and to determine overall maintenance frequency requirements. The following are lessons the City has learned during the inspection and maintenance of the project:

- **Debris and trash collection needed to be performed year-round:** while debris is routinely collected during the growing season at the same time as plant and bioretention maintenance, maintenance activities were scheduled less frequently during the winter, causing a significant amount of debris build-up between visits. Scheduling more frequent visits for debris cleanup in the winter was found to be beneficial

- **The majority of the plantings performed well:** Over 95% of the plants were found to be healthy at the completion of the 2-year warranty period, resulting in a relatively low level of additional plantings that were needed to fill-in gaps in the bioretention
- **Some mild erosion was found to occur:** With a number of overland flow paths to the bioretention, some locations were found to channelize and start to erode; ongoing maintenance and surface grading helped to correct some of those issues in the first two years to limit any additional long-term issues

Figure 4 and 5. South Side Settlement Heritage Park Post Construction

CONCLUSION

The design and construction of the South Side Settlement Heritage Park was one of the first green infrastructure projects to be completed as part of the Blueprint program. There was a significant need for coordination between City departments as well as with the general public in order to make the project a success. Each of the departments as well as the neighborhood associations provided feedback that was incorporated into the design of the park. This information helped to make the reaction to the final facility extremely positive. With the City’s Blueprint program looking to install many more green infrastructure facilities over the next 20-30 years, it was critical to understand and incorporate the lessons learned into future projects.

One of the biggest lessons learned was to begin public interaction and meetings even earlier in the process and to expand the areas where the public would provide input. On future Blueprint projects, the public was involved prior to any design drawing development and was also consulted on specific types of items in the final design, including the types of plantings and the specific aesthetics of any features included, including any paver or block wall selection. The new level of public involvement sought to reduce the potential of any negative public feedback regarding design features. In addition, more concepts were provided in future public meetings to solicit preferences among individuals in the affected neighborhoods to allow for more input and collect more data on preferences among the public.

The City is also developing a long-term maintenance and inspection program based on the information collected at the South Side Settlement Heritage Park following construction. This program will help to create a more proactive response to maintenance issues at bioretention cells across the City, creating a more successful Blueprint program and improving the aesthetics and performance of the stormwater facilities.

Overall, it is critical to the success of the Blueprint program and City's long-term wet weather management program to develop sustainable solutions that will continue to perform and provide benefit into the future. A key aspect of this work is collecting and soliciting feedback from City departments and the general public early on in projects to minimize rework and schedule delays, saving time and money. Increasing costs due to changes caused by a lack of communication have the potential to limit the effectiveness of the Blueprint program and affect the City's ability to meet their schedule and their budget. Working through the South Side Settlement Heritage Park was a success because of the coordination and input of all stakeholders; the City is continuing to increase those efforts on future projects to ensure that the overall Blueprint program is a long-term sustainable solution to their wet weather issues.

TOPKAPI Model and Its Application of Flood Early Warning and Forecasting in China

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ABSTRACT

TOPKAPI (tographic kinematic approximation and integration) model is a distributed hydrological model with physical mechanism developed by Prof. Ezio Todiniin and his team in Italy at the beginning of the 21st century. It can fully consider the spatial variability of rainfall, topography, vegetation, soil, and other factors. The TOPKAPI model is simple in structure and in parameter composition, so it has great advantages in real-time flood forecasting in river basins. On the basis of introducing the basic principle and structure characteristics of the TOPKAPI model, this paper explains the terrain data, hydro-meteorological data, soil, land use, and other data needed for the application of TOPKAPI model and the acquisition ways or approaches of the data. Then it analyzes the application of TOPKAPI model in the world, especially the application of flood forecasting in China. Finally, the TOPKAPI model is compared with TOPMODEL model, SWAT model, and lumped Xin'anjiang model. It points out that TOPKAPI model has great application potential in real-time flood forecasting, but it is inadequate in the areas where human activities are intense. It is necessary to combine other methods or models to improve the simulation process and the simulation effect, and it is also need to develop concurrent application versions of the network to meet the need of real-time flood forecasting of some departments at the same time. The research results may provide some reference for the improvement of TOPKAPI model and its application and popularization in real-time flood early warning and forecasting in China.
Key words: Distributed hydrological model; TOPKAPI; Flood forecasting; Ungauged basins

In recent years, with the advancement and development of remote sensing (RS), geographic information system (GIS), computer technology and technology improvement in other fields, the research method and application of distributed hydrological models have been continuously improved, and they have become effective method to simulate and predict cross-section flow of a river. The combination of distributed hydrological model and spatial data such as digital elevation model (DEM), land use and soil data can not only reflect the evolution law and hydrological processes of hydrological cycle at different time and space scales, but also can provide a more efficient framework and platform in a comprehensive solution to solve a variety of issues closely related to the water cycle (ZHAO jun et al. 2011). This paper mainly discusses the basic principle of the TOPKAPI (TOPographic Kinematic APproximation and Integration) model, one of the distributed hydrological models based on physical mechanism, and its application in flood forecasting, aiming to improve and promote its application in flood forecasting in China.

BASIC PRINCIPLE OF THE MODEL

TOPKAPI model is developed on the basis of ARNO and TOPMODEL, proposed by Professor Ezio Todini of the University of Bologna in Italy in 1995. It was originally a physical rainfall-runoff model, which was designed to mine the potentiality of distributed hydrological models based on physical mechanism, and to overcome the shortcomings of the parameter values vary by scales in the TOPMODEL model, so it can be applied to the different spatial scales from slope to watersheds (Cinzia Mazzetti et al. 2014). Later, the European Commission and the Spanish government funded the development of the model. In 2000, PROGEA srl. founded as a University Spin-off, through the collaboration among University of Bologna, ARPA Emilia-Romagna, CAE Spa and ET&P Srl., under the guide of Prof. Ezio Todini, to develop the model. The development team completed the model code in 2001 and began to apply this model, in the next years, the code was further optimized, and some modules/methods were added; then in 2013, the model suite consisted of four parts: Pre-Processing (PreTPK), Model Parameter Management (ITOPKAPI), Model Results Display Interface (TPKVIEW), and the State Chart Display section (TPKMAPS).

The TOPKAPI model is a fully distributed hydrological model with physical mechanism. It can fully consider the spatial variability of rainfall, topography, vegetation, soil and other elements, and its model structure and the parameter scheme is simple. It is one of the several distributed hydrological models in operation in the world, and it is also the component and core module of the European Flood Forecasting System (EFFORTS).

Basic Methodology

The model is based on the idea of combining the kinematic approach and the topography of the basin, which subdivides the application domain by means of a grid of squared cells, whose size generally increases with the overall dimensions. As a computing unit, its input (precipitation) is provided by rain gauges or weather radar. The spatial distribution of characteristic parameters, precipitation and hydrological response of a watershed is simulated by grids in the horizontal direction, and while the horizontal soil column corresponding to each grid in the vertical direction. The model integrates the runoff generation and confluence, using DEM to automatically generate the confluence path of each water drop in a grid to the outlets of the basin. According to the confluence path, the model describes the hydrological and hydraulic processes of rainfall-runoff in a basin through three ‘structurally-similar’ zero-dimensional non-linear reservoir equations. Then the equations are integrated on each grid, and each grid is a computational node that reflects the physical properties of the model (mass balance and momentum balance).

The TOPKAPI model can describe the main hydrological processes of the basin's hydrological cycle, considering not only the surface flow, soil water, groundwater, but also the infiltration, evapotranspiration, snow melting, reservoir/lake flood control, and the one-dimensional flood routing with the modified Muskingum-Cunge method. The basic assumptions of the TOPKAPI model are(Cinzia Mazzetti 2015): 1) Precipitation is assumed to be constant over the integration domain (namely the single cell); 2) All the precipitation falling on the soil infiltrates into it, unless the soil is already saturated in a particular zone; 3) The slope of the water table is assumed to coincide with the slope of the ground, unless the latter is very small (less than 0.01%), this constitutes the fundamental assumption of the approximation of the kinematic wave in the De Saint Venant equations, and it implies the adoption of a kinematic wave propagation model with regard to horizontal flow, or drainage, in the unsaturated area; 4) Local transmissivity, like local horizontal flow, depends on the total water content of the soil, i.e. it depends on the integral of the water content profile in a vertical direction; 5) Saturated hydraulic conductivity is constant with depth in a surface soil layer but much larger than that of deeper layers; this forms the basis for the vertical aggregation of the transmissivity, and therefore of the horizontal flow.

Model Structure

The model is generally divided into components of plant interception, snow melting, evapotranspiration, infiltration, percolation, surface flow, subsurface flow, underground flow, channel flow, reservoir/lake and discharge. The model structure and flow simulation steps are shown in Figure 1.

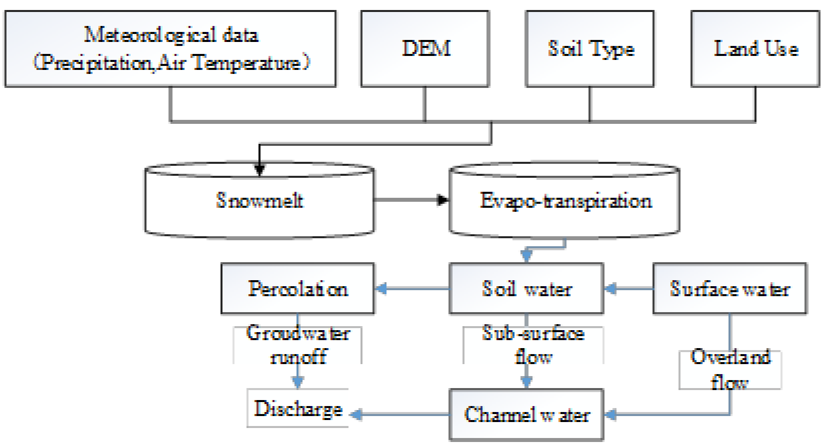

Figure. 1 Flow simulation steps of the TOPKAPI model

①Plant interception component, it uses the hydro-meteorological data, parameters of land use and a simple empirical equation to calculate the maximum plant interception and net precipitation. ②Snowmelt, it estimates the amount of radiation based on the measured temperature, and then calculates the amount of snowmelt for each cell based on energy and mass balance. The required input parameters are rainfall, temperature, and the radiation. ③Evapotranspiration, the calculation of evapotranspiration includes two parts, plant evapotranspiration and soil evaporation. In the case of having only precipitation and temperature data, the model uses the Thornth-waite formula to calculate the monthly average evapotranspiration. Then the evapotranspiration capacity is calculated according to the plant type and the period of plant growth, while according to the soil water and the cover to calculate the actual evapotranspiration. In the higher altitude area, the Blaney-Criddle formula can be used to calculate the evapotranspiration of some grids, when the elevation limit can be set in advance. ④Infiltration, the infiltration of rainfall replenishes the upper layer of soil, and a part of the water penetrates from the upper layer of soil to the lower layer of unsaturated soil, and then further into the lower layer of saturated soil, and then do horizontal movement. When the groundwater level rises to the upper soil, the lower unsaturated soil layer temporarily disappears (LIU Zhiyu 2005). The infiltration capacity depends on the type of vegetation and the soil storage. The actual amount of infiltration is calculated by comparing the infiltration capacity with the surface water volume (including precipitation). ⑤Subsurface flow, the soil flow at a certain point can be approximated by the kinematic wave and a non-linear reservoir equation, which is solved by numerical and analytical method, so as to calculate the average subsurface flow of each grid and the amount of subsurface flow in the time period according to the water balance principle. ⑥Surface flow, similar to the subsurface flow, the Manning formula is used to approximate the momentum equation and a non-linear reservoir equation is got in the vertical direction for each grid. ⑦Underground flow, it uses a linear reservoir model to calculate groundwater level and underground runoff. Based on the percolation of the upper soil layer and the saturation of the lower soil layer, the empirical formula is used to determine the vertical recharge of groundwater. ⑧Channel flow, similar to the subsurface flow, it applies Manning's law of resistance, approximating the motion of water on the ground and in any horizontal direction of the river (momentum equation) by kinematic wave, and a non-linear reservoir equation can be obtained for channel runoff. As for river flood routing, when the river slope is less than 0.1%, the Muskingum-Cunge-Todini method is used to replace the kinematic wave non-linear reservoir method, and the hydrodynamic flood routing method is used for the channel with larger slope. ⑨Reservoir/lake, assuming that the reservoir is a multi-input, single-output system, the inflow of the reservoir is obtained by adding the out flow of all inflow grids of the reservoir and the rainfall in the reservoir, then subtracting the water surface evaporation. On the basis of the reservoir dispatching rules, according to the principle of water balance, the reservoir flood control calculation is carried out.

The TOPKAPI model is currently loosely coupled with Map Window GIS and runs as a plug-in for Map Window GIS. The visual interface consists of four different modules: ①PreTPK, is mainly responsible for the basic data inputting, processing and sub-basin division of the model, including watershed delineation, working area, importing maps, finding and confirming outlets, creating water net, and calculating physical parameters, and also editing DEM/river, inputting monthly data, managing stream, and exporting output points. This part uses the MWGIS interface to display, and some of this work can also be done in other GIS tools, but it must be completed before proceeding. ②ITOPKAPI, is responsible for parameter inputting/setting and modification of various parts of the model, as well as general settings, time-state, stations, maps, river channel width, initial condition, soil, land use, channel, outputs, temperature, evapotranspiration and ET-snowmelt, reservoirs, inter-basin, inflow and outflow. ③TPKVIEW, including modules of selecting simulation, output points, inter-basin analysis/contribution, reservoirs, inflow points, outflow points, soil type/land use (basin/inter-basin) and so on, can analyze and display the one-dimensional results of a completed project. ④TPKMAPS, mainly shows the results of two-dimensional state diagrams of a certain completed project, such as rainfall, temperature, flow, actual/potential evaporation, percolation, snow(SWE), soil moisture, and surface flow. The states of these time-varying variables will be dynamically displayed in WMGIS interface according to the time-setting step.

Model Characteristics

All steps of the model's application are completed in the same environment, including the preprocessing, initial parameter inputting, calculating process, and results displaying, which greatly improves the efficiency of data analysis and decision making. The main characteristics of the model are described below: ①It has short calculation time and fewer parameters, and can be coupled with hydraulic models (such as HEC-RAS and SOBEK, which makes it possible to make real-time flood forecasting. ②The model parameters do not lose its physical meaning although the grid size of the calculation unit ranges from 100m to 1km, and the calculation period is from few minutes to 24 hours. ③The parameter calibration is simple and convenient, and most of them come from various thematic maps, such as DEM, soil, land use/vegetation maps, only a few are obtained by commonly used parameter calibration method. ④It can fully consider the non-uniformity of spatial and temporal distribution of precipitation, which improves the input precision of precipitation by integrating multi-source precipitation information, such as ground rainfall observation and meteorological radar rainfall estimation data. ⑤It can flexibly give the outflow anywhere on the river network (one-dimensional output). ⑥It can describe the internal changes of the hydrological response of the basin by giving the spatial distribution thematic maps of all major hydrological state variables (soil moisture, flow, snowmelt, evapotranspiration, etc.) in a specific time step. ⑦It can be used either offline lonely or as a flood forecasting model for a real-time flood operation systems for continuous simulation or forecasting. ⑧With the “3S”technologies, the model can be applied to watersheds without runoff observation data, and can be used for different scenarios (climate change, water resource managements, etc.).

Model Parameters and the Determination

The basic data needed in the model includes DEM, soil and land use, precipitation, temperature, etc. Table 1 lists the basic parameters required in some processes and their meanings.

Table 1 Basic parameters required for the TOPKAPI model (LIU Zhiyu 2004; LIU Zhiyu et al. 2003)

Sub-process	Parameters
Interception	Water storage capacity of leaf, Plant interception capacity, Cover index, Plant leaf area index
Snowmelt	The critical temperature of rain or snow, Albedo
Evapotranspiration	Plant growth index, Ratio of actual Evapotranspiration to evapotranspiration capacity
Infiltration	Conversion coefficient of precipitation to soil infiltration
Surface flow	Manning roughness coefficient (Surface, Channel), Width of channel section
Upper soil layer (percolation and soil flow)	Soil layer thickness, Saturated conductivity, Saturated volume water content, Field water holding capacity, Wilting coefficient, and other indexes reflecting soil conductivity
Lower soil layer (groundwater recharge and underground flow)	Elevation of impervious layer, Soil saturated hydraulic conductivity, Effective soil porosity and other index reflecting soil percolation characteristics

In theory, the value of a parameter with a clear physical meaning does not need to be calibrated and can be directly measured. However, since the measured value is based on some points, the representativeness is insufficient, and some parameters have large variations in