# The Integrated model HydroGis for modelling/predicting Flood and Mass Transport and its Applications in River Deltas of Viet Nam

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***ABSTRACT***: *Almost Vietnamese people are living in river deltas flooded by upstream flows, tide, storm surge, storm rainfall and intruded by marine salinity in dependent of weather in region with tropical monsoon climate. In addition, environment here has very serious challenges induced by domestic and industrial wastes and environmental incidents. Present problems deal with new complicated hydrodynamics features introduced by engineering developments and urbanization (Dykes, channels, sluices, roads, harbor, shrimp ponds and other infrastructures). This requires development of a methodology, database and integrated tools for management and prediction of water resources, water quality, floods, salinity intrusion, environmental impacts of infrastructure developments. This is carried out by an integrated model "*__HydroGis__*" developed in Hydro-Meteorological Service of Viet Nam, which is briefly described here. The* **HydroGis** *is hydraulic model of four-in-one included hydrodynamic model, mass transport model, special input/output database managed GIS tools and friendly interface windows. It's operating as assistant tools for modelling/predicting/managing surface water resource, flood and mass transport in Mekong river delta and another river deltas of Ho Chi Minh City, Khanh Hoa, Dong Nai…provinces. Some results of its applications will be showed in this paper too, including databases in GIS of: (i) water level, discharge, deep of inundation and water balances; (ii) all parameters modeled spreading and decay of organic pollutant wasted from domestic area, industrial zone; (iii) spreading and weathering spilled oil in river deltas.*

## 1. Introduction

The unsteady flow and mass transport in river delta, where interaction of upstream flows, coastal sea dynamics and engineering developments, urbanization (Dykes, channels, sluices, roads, harbour, shrimp ponds and other infrastructures) is very complicated, are big objects for many Hydro-Meteorological and environmental scientist and organizations. At present, there are many models for flood, salinity intrusion and spreading substances. Most of them had packaged in form of computer software as: MIKE 11 (Denmark), ISIS (UK), CanalCAD (USA), riverCAD, UNET (USA), FLDWAV (USA), CASCADE (French), SOGREAH (French), TeleMAC (EU); Master model (Holland); KOD (Viet Nam); VRSAP (Viet Nam); SAL (Viet Nam); **HydroGis** (Viet Nam), TiCAD (Germany), SOBEK (Holland), FEQ(USA), TL(Viet Nam)…… There are some problems in foreign model application related with database standards, data management, model modification and rationalization, local experience... Thus, their application in Viet Nam is not enough effective. Another side, the local models are good in hydrodynamic simulations, but most of them are not friendly, without GIS linking and difficult for operating and data management. With inheriting the previous fundamental studies and orienting to applying for Vietnamese conditions, we have developed assistant software **HydroGis** for controlling flood, salinity and mass transport in low river system and river mouths. As packaged computer installing software, its first version was created in 1995. During ten years of its development, it becomes a more powerfully applied computer software and has wide application in Viet Nam. Particularly, it had been used in many projects such as in Mekong River delta, Sai Gon-Dong River basin, Thi Vai river basin, Cai River delta, Dinh river basin and Red river delta [1-4, 7-25].

## 2. The basic philosophy

The philosophical fundamental point of **HydroGis** is linking databases, knowledge bases, model-base, GIS and computer tools into **single assistant independent software**. The its main engines had made from the **hydrodynamic models** and special **GIS** models for river basin. The principal structure of this model is showing on figure 1.

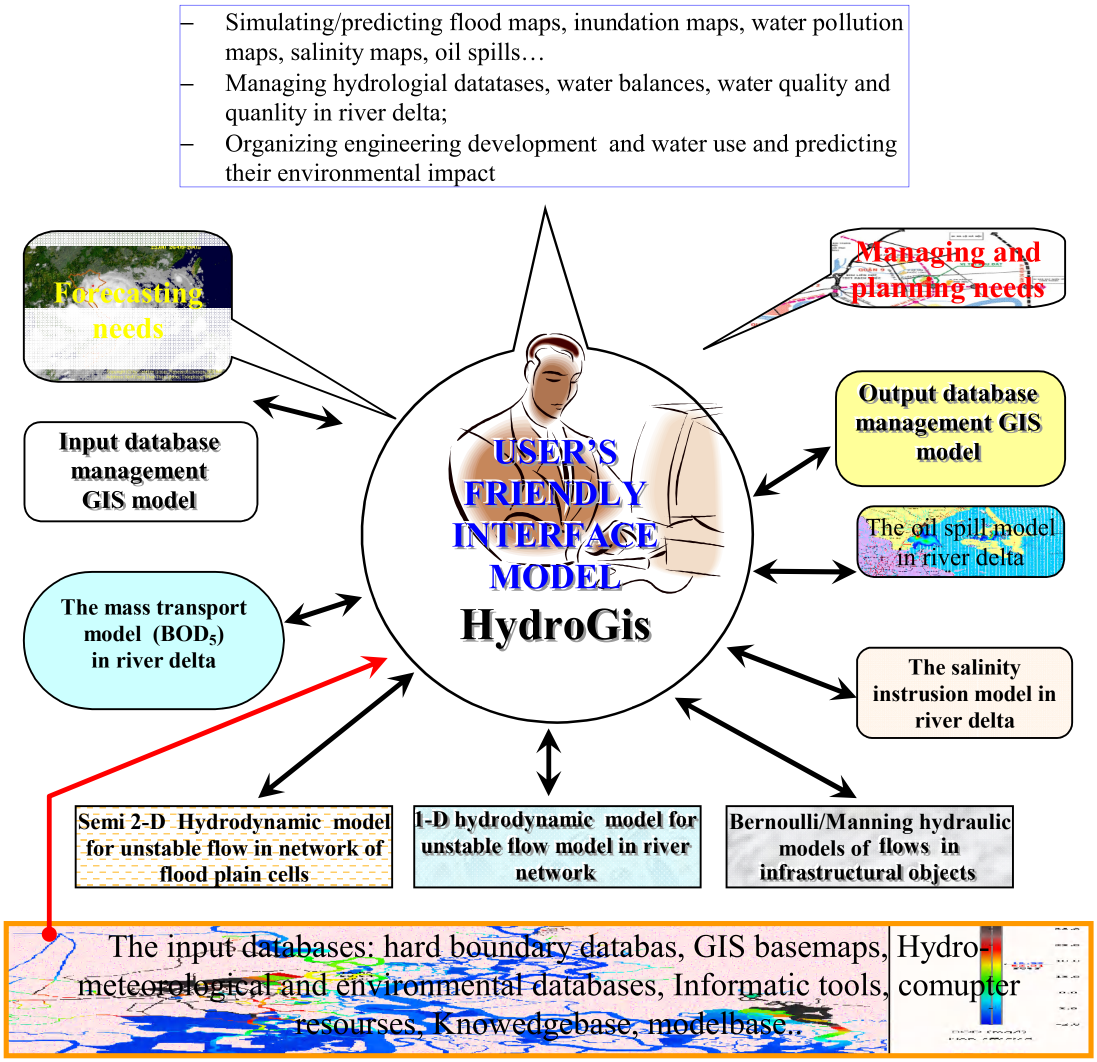



Figure 1. The prinsipal structure of **HydroGis** model

## 3. The summary on hydrodynamic models

The Hydrodynamic models of **HydroGis** approximate mass transport and hydraulic laws for all surface water bodies in the river delta. They operate on two fundamental databases: the hard boundary database, Hydro-meteorological and environmental database. The hard boundary database includes network of river cross-sections, network of flood plain cells and network of intrastructure objects (sewers, dyke, dam, sluices, bridge…). The figure 2 illustrates result of digitization of real picture to digital hard boundary database in **HydroGis**.

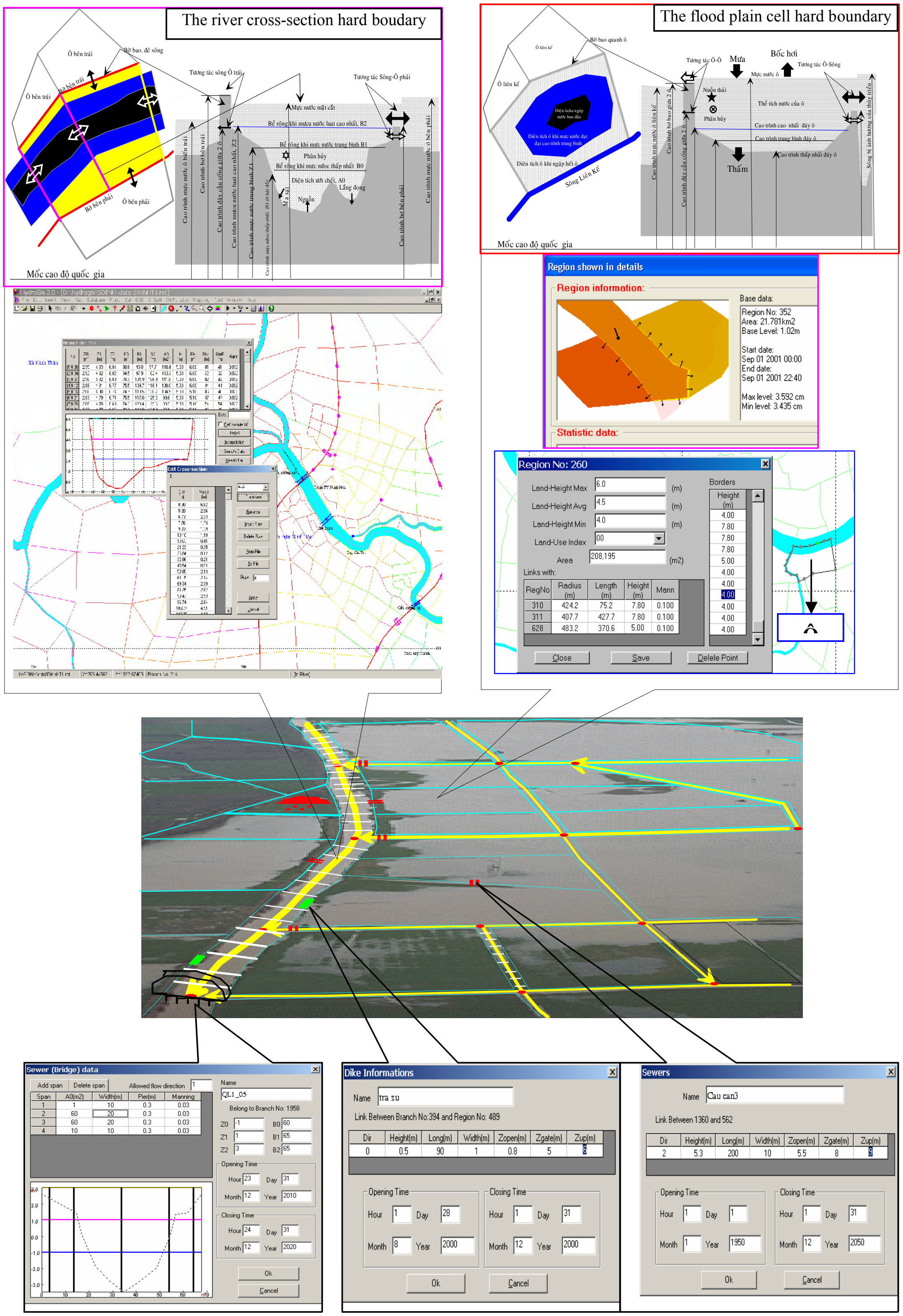



Figure 2. The database structure of hard boundary approximated river delta basin in **HydroGis**

There are two main objects: flood plain cell and cross-section. The **cell** is any polygon had hard border of fixed height and length and water boundaries contacted with another water bodies (sluice, sewer..). The cell bottom surface is approximated by DEM. It also has coordinates of centre, land use index and another characteristic. The total research basin area will be filled cell by cell. The cell interacts with another cell and river creek through the border height and hydro-technical constructions. The cell has own salinity, water level, and water volumes, manning coefficient, discharges to/from cell, rainfall, evaporation and infiltration/groundwater flow, wind characteristics. The river cross-section has wet area, hydraulic radius, widths at any water level. It also may have sewers, bridges, right dams, left dams and another characteristic. The cross-section has own salinity, water level, and concentration of mass substance, water discharge and another hydraulic parameters. The cross-section interacts with cell through right and left dams. The river branch is made from some cross-sections by sequential linking cross-section by cross-section. The river network is made by connecting branch by branch. The full river delta basin will be modelled by combining river network, river basin filled cell by cell and network of constructions. The all types of linking and interacting cell⇔cell, cell⇔Cross-section and cross-section⇔cross-section are made by true geographical coordinates and by mathematical equations expressed mass transport and hydraulic laws.

**The basic equations:**

Interaction between cross-sections is modelled by Saint-Venant system of equations and equations of mass balance as following:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c \qquad (1.a)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left[\frac{Q^2}{A}\right] + gA\frac{\partial Z}{\partial x} + \frac{gAQ|Q|}{K^2} - C_w BWW_x - \theta gA(R\frac{\partial S}{\partial x} + S\frac{\partial Z}{\partial x}) + q_c \cos\alpha \frac{Q}{A} = 0 \quad (1.b)$$

$$\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x} - \frac{\partial}{\partial x}\left[E_s \frac{\partial S}{\partial x}\right] = -[(q_{out}^L + q_{out}^R)S + (q_{in}^L S_L + q_{in}^R S_R)]/\mathrm{A} \qquad (1.c)$$

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} - \frac{\partial}{\partial x}\left[E_c \frac{\partial C}{\partial x}\right] = -[(q_{out}^L + q_{out}^R)C + (q_{in}^L C_L + q_{in}^R C_R)]/\mathrm{A} + \text{source - sink} \quad (1.d)$$

$$q_c = q^L + q^R,\ \ q^R = q_{in}^R - \mathrm{q}_{\mathrm{out}}^{\mathrm{R}},\ \ \mathrm{q}^{\mathrm{L}} = q_{in}^L - \mathrm{q}_{\mathrm{out}}^{\mathrm{L}},\ \ \mathrm{K}^2 = \frac{A^2 R^{4/3}}{n^2} \qquad (1.e)$$

$$E_{\mathrm{S}} = E_{\mathrm{C}} = E_0 + C_E(\mathrm{A}\Delta x)^{2/3}\left|\Delta U/\Delta \mathrm{x}\right|,\ E_0 = 0.5 - 1.0 m^2/s, C_E = 0.01 \qquad (1.f)$$

Where:

- *Q is discharge, $m^3/s$;*
- *A is wet area of cross-section, $m^2$;*
- *$q_c$ is total lateral discharge per unit of length, $m^2/s$;*
- *q with index of $^{L,R}$ is lateral discharge from cells placed on left and right sides of river per unit of length, $m^2/s$ ;*
- *q with index of $_{in,\ out}$ is discharge per unit of length to/from river by interaction with linked cells placed on left and right sides of cross-section, $m^2/s$;*
- *B is width in river surface, m;*
- *S is salinity in river, g/l;*

- *S with index is salinity of left/right linked cell to cross-section, g/l;*
- *R is hydraulic radius, m;*
- *$\alpha$ is angle of lateral flow to river axis, rad.;*
- *$C_w$ is wind friction coefficient;*
- *$E_s$ is salinity dispersion coefficient, $m^2/s$;*
- *W, $W_x$ are wind speed and component of wind direction to river axis.*
- *$E_c$ is mass dispersion coefficient, $m^2/s$;*
- *T is half-life period of substance;*
- *Sink is decay rate of substance by Bio-Chemical-physical effects,* mg/l/s*;*
- *Source is induced rate of substance by Bio-Chemical-physical effects,* mg/l/s*;*
- *N is Manning coefficient;*
- *K is Discharge coefficient;*
- *U is cross-section average flow velocity, m/s;*
- *C is concentration of substance in river, ml/l;*
- *C with index is concentration of substance in the cell, ml/l;*
- *$\theta$=$8.0210^{-5} m^3/kg$ is experimental coefficient;*
- *Cw=$2.610^{-5}$ is experimental coefficient of wind stress;.*

The changes of water volume V, salt mass (VS) and substance mass (VC) induced by processes:

1. Total flows of water and mass between cell and river: $Q_{c\text{-}o}$, $QS_{c\text{-}o}$, $QC_{c\text{-}o}$
2. Total flows of water and mass between cells: $Qo_{\text{-}o}$ $Q^{So}_{\text{-}o}$, $QCo_{\text{-}o}$;
3. Rainfall and its impacts on mass balances: P, (-PS) and (-PC);
4. Evaporation and its impacts on mass balances: (-E), (ES) and (EC);
5. Infiltration/groundwater flows: ±Inf
6. Bio-Chemical-physical loading of mass: **source**;
7. Bio-Chemical-physical decay of mass: **sink;**
8. Incoming mass from point and surface sources: $Q_w$, $Q_s$, $Q_c$

are modelled by equations of energy, momentum and mass balance as following:

$$\frac{dV_i}{dt} = Q_{o-o} + Q_{c-o} + P - E + Q_W \pm \text{Inf},$$

$$Q_{o-o} = \sum_{j=0}^{o\_in} Q_{ji} - \sum_{j=0}^{o\_out} Q_{ij}, \quad Q_{c-o} = \sum_{c=0}^{C\_in} q_{ci} - \sum_{c=0}^{C\_out} q_{ic} \tag{2.a}$$

$$\frac{d(V_i S_i)}{dt} = Q^S_{o-o} + Q^S_{c-o} - P_i S_i + ES_i + Q_S,$$

$$Q^S_{o-o} = \sum_{j=0}^{o\_in} Q_{ji} S_j - \sum_{j=0}^{o\_out} Q_{ij} S_i, Q^S_{C-O} = \sum_{c=0}^{c\_in} q_{ci} S - \sum_{c=0}^{c\_out} q_{ic} S_i \tag{2.b}$$

$$\frac{d(V_i C_i)}{dt} = Q^C_{o-o} + Q^C_{c-o} - P_i C_i + EC_i + \text{sink}_i + \text{source}_i + \text{Q}_C,$$

$$Q^C_{o-o} = \sum_{j=0}^{o\_in} Q_{ji} C_j - \sum_{j=0}^{o\_out} Q_{ij} C_i, Q^C_{c-o} = \sum_{c=0}^{c\_in} q_{ci} C - \sum_{c=0}^{c\_out} q_{ic} C_i \tag{2.c}$$

Where:

- $S_i$, $C_i$ *are* salinity and concentration of substance in cell *i;*
- $S_j$, $C_j$ *are* salinity and concentration of substance in cell *j;*
- $Q_{ij}$ *is* total discharge from cell i to cell j*;*

- $Q_{ji}$ is total discharge from cell j to cell i;
- $q_{ci}$ is total discharge from cross-section to linked with it cell i;
- $q_{ic}$ is total discharge from cell i to with it cross-section;
- *o_in* is total number of cells flowed to cell i;
- *o_out* is total number of cells flowed from cell *i;*
- *c_in* is total number of cross-sections flowed to cell i;
- *c_out* is total number of cross-sections flowed from cell i;

The $Q_{ij}$, $Q_{ji}$, $q_{ci}$, $q_{ic}$ in equations (2.a)→(2.c) are summary of two components: overflow over cell's border heads and flow through sewers, sluices, dike breaking of cell's and river's border. The value and direction of overflows and flows through constructions of cell and river had been modeled by Bernoulli or manning formulas in dependent of flow properties (full free, shallow submerged or deep submerged flow as showed in [7,8]).

The new parameters related to equations of (2.a)→(2.c) are: averaged water level in cell; cell's area with given water level; water depth in cell; Height, width and length of borders; radius between linked cells and cross-section; geometry and hydraulic parameters of hydro-technical constructions; cell's land cover surface properties….

The system of equations (1)-(2) is closed with 5 variables: Q, $\zeta$, V, S and C for all river cross-section network and floodplain cells. The described model above is non-linear.

The initial conditions are given values of all arrays Q, $\zeta$, V, S and C for total river cross-section network and floodplain cells. The model **HydroGis** provides two options to set initial databases called as cold starting (value all of them will be set to zero) and hot starting that value of Q, $\zeta$, V, S and C for all river cross-section network and floodplain cells will be assigned from preview database. The last one is very important in application of **HydroGis** as forecasting tool for large river basin as Mekong river delta.

The boundary conditions will be as following:

- At a downstream node of river network (river mouths):
  - $\zeta(t) = Z_s(t)$;
  - $S(t)=S_s(t)$ when flow directs to river;
  - $C(t)=C_s(t)$ when flow directs to river.
- At a upstream node river network (inflow of water, waste sources):
  - $Q(t)=Q_o(t)$;
  - $S(t)=C_o(t)$ when flow directs to river;
  - $C(t)=C_o$ (t) when flow directs to river.
- At a joint node of river network:
  - Water level is the same for all jointed river cross-sections at this node;
  - Algebraic sum of incoming and out coming water flows will equal 0;
  - Algebraic sum of incoming and out coming mass flows will equal 0.

The model **HydroGis** provides **some options** to set boundary databases: traditional tools for importing measured data to boundary databases; modelling tools for some predicting hydro-meteorological parameters as tidal water lever, storm surge water level.... Thus, **HydroGis** can be used in **both options**: simulating and forecasting.

**<u>The numerical solution:</u>**

The system of equations (1)→(2) with included boundary conditions will be solved by numerical method by some iteration cycles. Specially, calculating steps are following:

1. *Step 0: update values of input database for next time step (boundary conditions, geometrical data…) and values of all variables at present time step;*
2. *Step 1: Solute problem of unsteady flow and mass transport for river network (system of equations 1.a→1.c for updating values of all variables of river network at next time step:*

- The Saint-Venant system of equations had been approximated by Preissmann technique. The received algebraic equations will be solved by direct methods.
- The mass transport model is solved by physical splitting method. First, the transport-dispersion equation is splitting into transport alone and dispersion alone. Next, transport problem will solved by characteristic-line technique, while dispersion problem will be solved by finite difference approximate method;

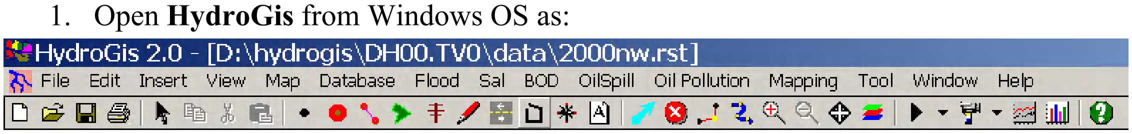
3. *Step 2: Solute problem of interactions between river network and linking cells will update lateral discharges of water and mass and water level and concentration of substances in linking cells by simple approximated method at next time step*;
4. *Step 3: Solve problem of interactions between cell and cells will solve for continued updating water level and concentration of substances in cells at next time step by Zeidel iteration method*;
5. *Step 4: update values of all variable for full system at new time step;*
6. *Step 5: check condition for finishing iteration process. If a finishing condition is satisfied, the next cycle will begin by step 0. If a finishing condition isn't satisfied, next calculating cycle will begin by step 1 and end by step 5.*

The maximal number of iteration cycles usually depends on time step end resolution of discretion of river network. For example, with time step $\Delta t$=900s and maximal distance between two nearest cross-section of the same river branch $\Delta x$=1500m, maximal number of iterations never greater 5 (for maximal relative error is 5% for Q of all river network) for Mekong river delta. But, the number of iterations will be increased if $\Delta t$ or/and $\Delta x$ increase. So, for each research case, user has to make some numerical experiment to choose optimal $\Delta t$ and $\Delta x$. **HydroGis** has option to make it easy.

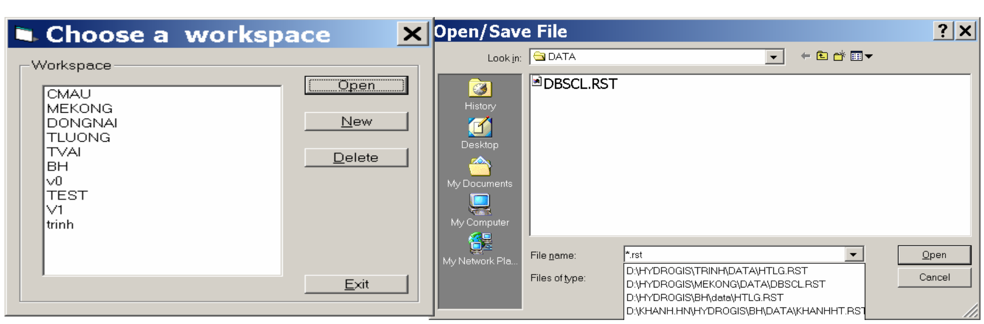
**<u>The run of hydrodynamic models:</u>**

The procedure to run **hydrodynamic models** inside **HydroGis** includes following steps:

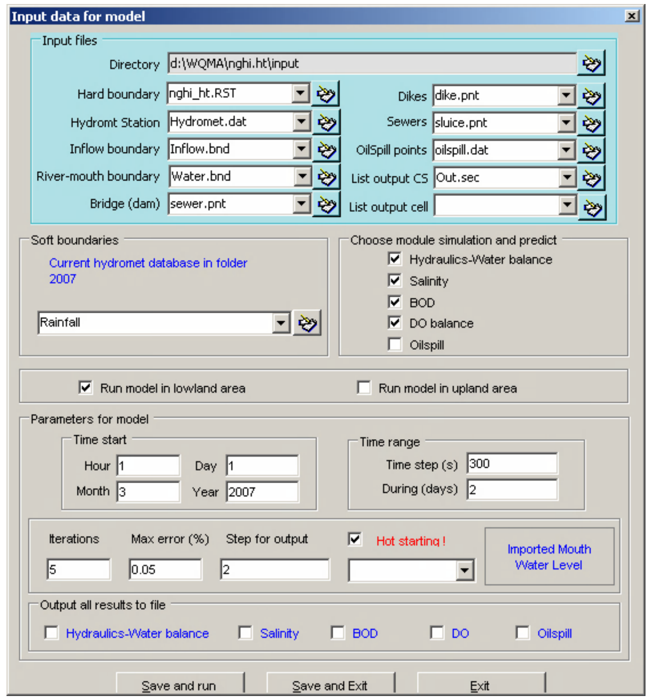
1. Open **HydroGis** from Windows OS as:



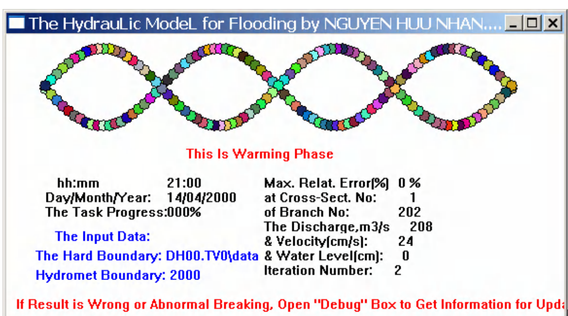

2. Make new **workspace** or open existed **work space** to perform**:**

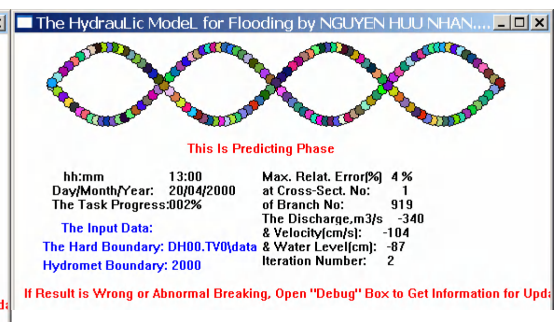


3. Create new or update/edit already existed input database by **HydroGis** GIS tools;
4. Linking objects and discretion river branches to cross-sections;
5. Preparing and edit hydro-meteorological input data by **HydroGis** data managed tools;
6. Choose the run regime (flood/salinity/pollution/oils spill.. modeling);
7. Choose hour, date of beginning, time period, time step to numerical experiments;
8. Click button "continue" to perform actual work;




9. Sit back and wait for completion of numerical experiments:




10. Use **HydroGis** for graphic, mapping, animation...tools to package the output products.

## 4. The GIS models.

The **GIS** models inside **HydroGis** are special: they are friendly, simple and effective for hydrological using for low river delta. They have been built from <u>interface tool</u> with MS WINDOWS 9x/2k standards, <u>database Management tools</u> with hydrological and hydraulic conceptions, <u>mapping and graphical tools</u> with vector methods of visualization; <u>Animation tools</u> with vector methods of visualization.

### <u>Interface tools:</u>

In the **HydroGis,** any interface is according to standard of MS WINDOWS. The Main menu includes toolbar, menu bar as showed below.

*Figure 3 The main menu bar of*

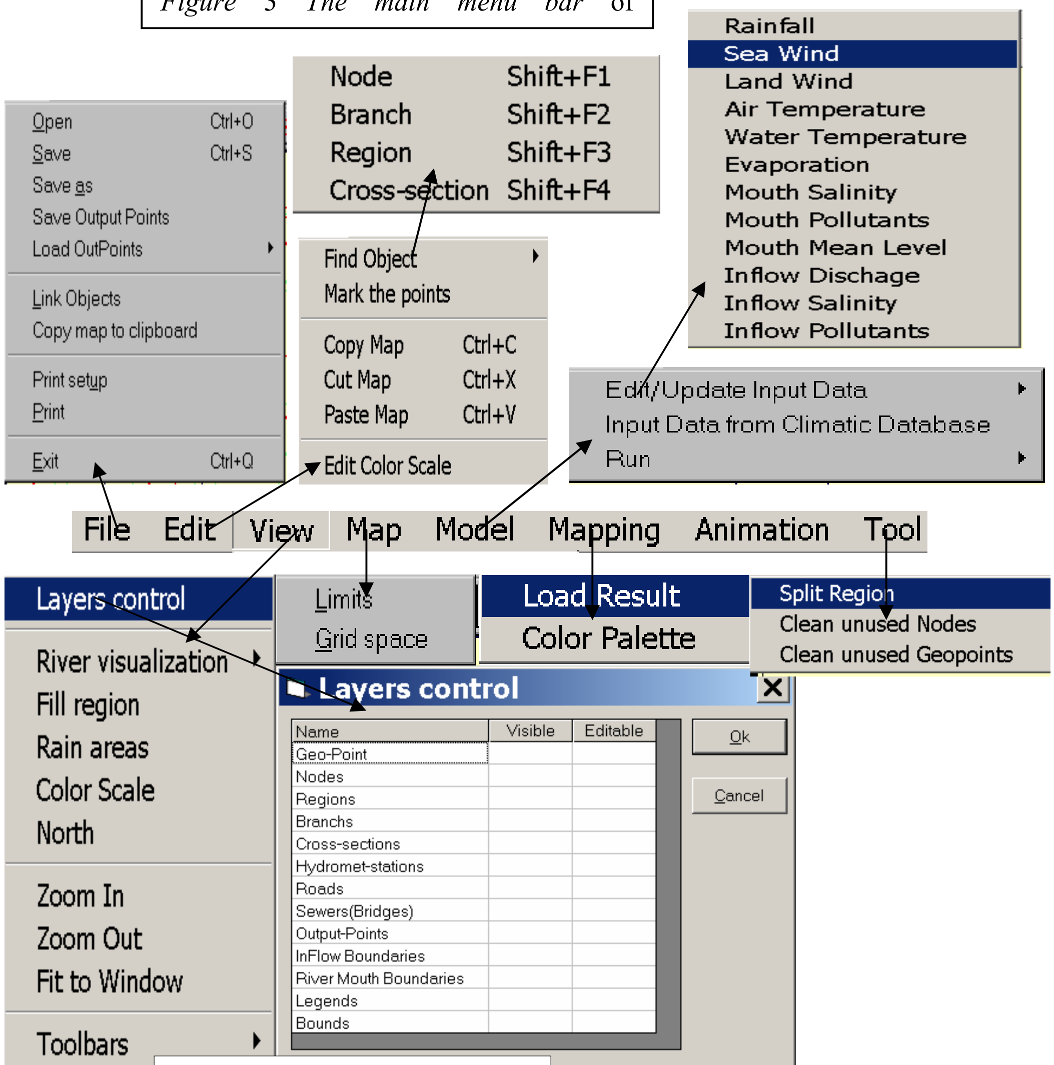
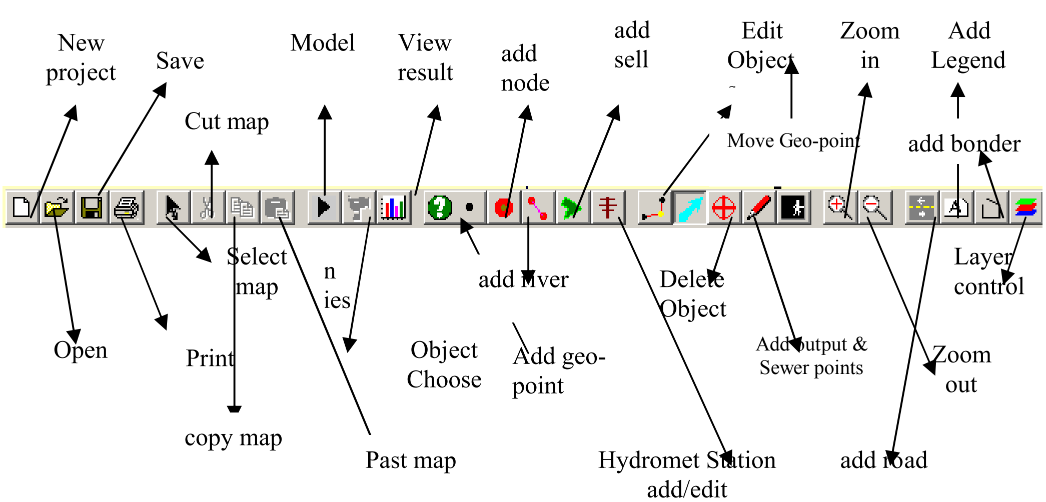


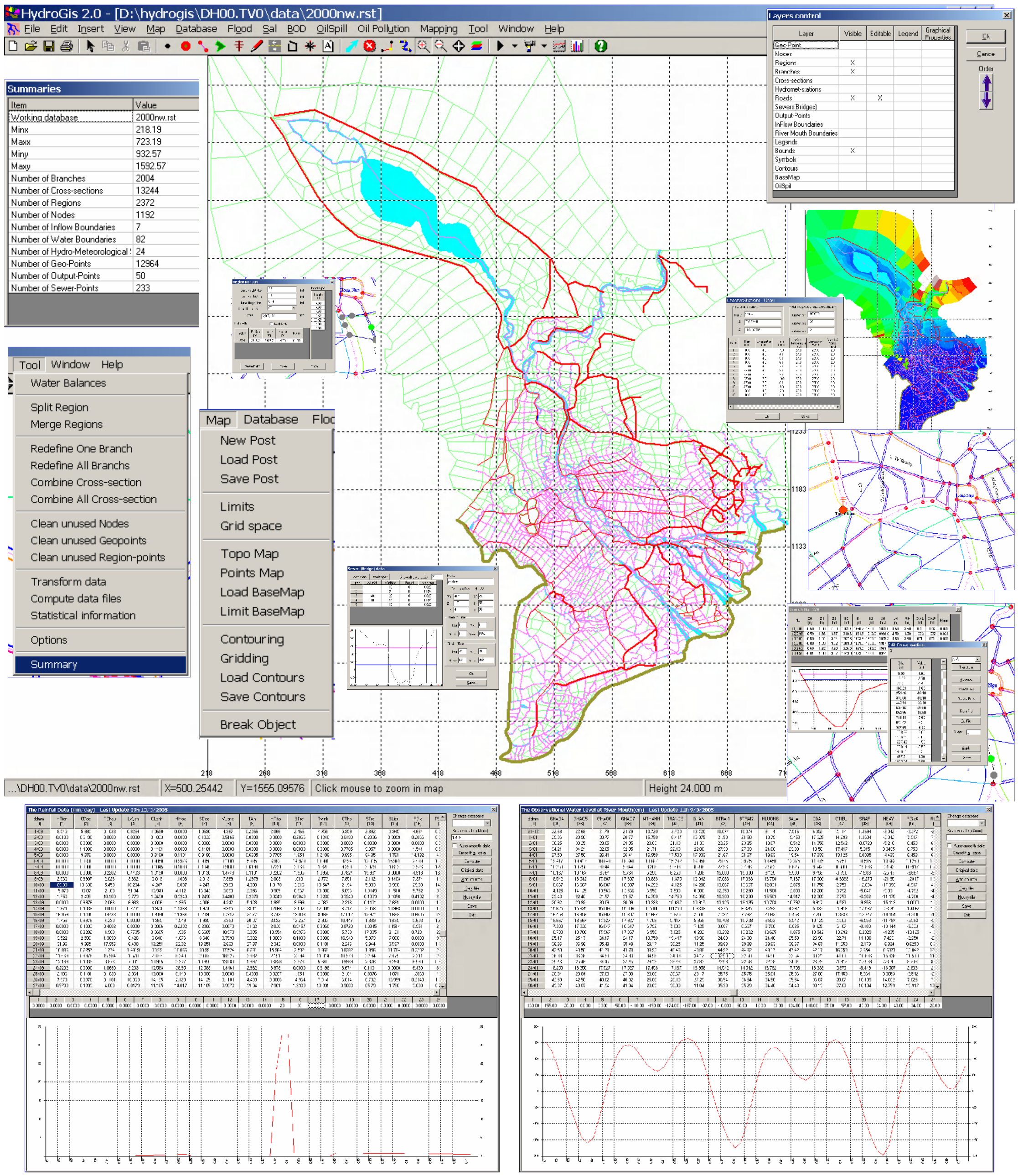

*Figure 4. Tool bar of*



## Database Management tools:

The database here is input data including all geometrical characteristics of river network, cell network; hydrological and meteorological data; roads; legend; boundary data; nodes; other data which have relation with flood and mass transport in river basin. Some of them are showed (example in lower Mekong river delta) as the following:

Figure 5. The input database management tools of HydroGis

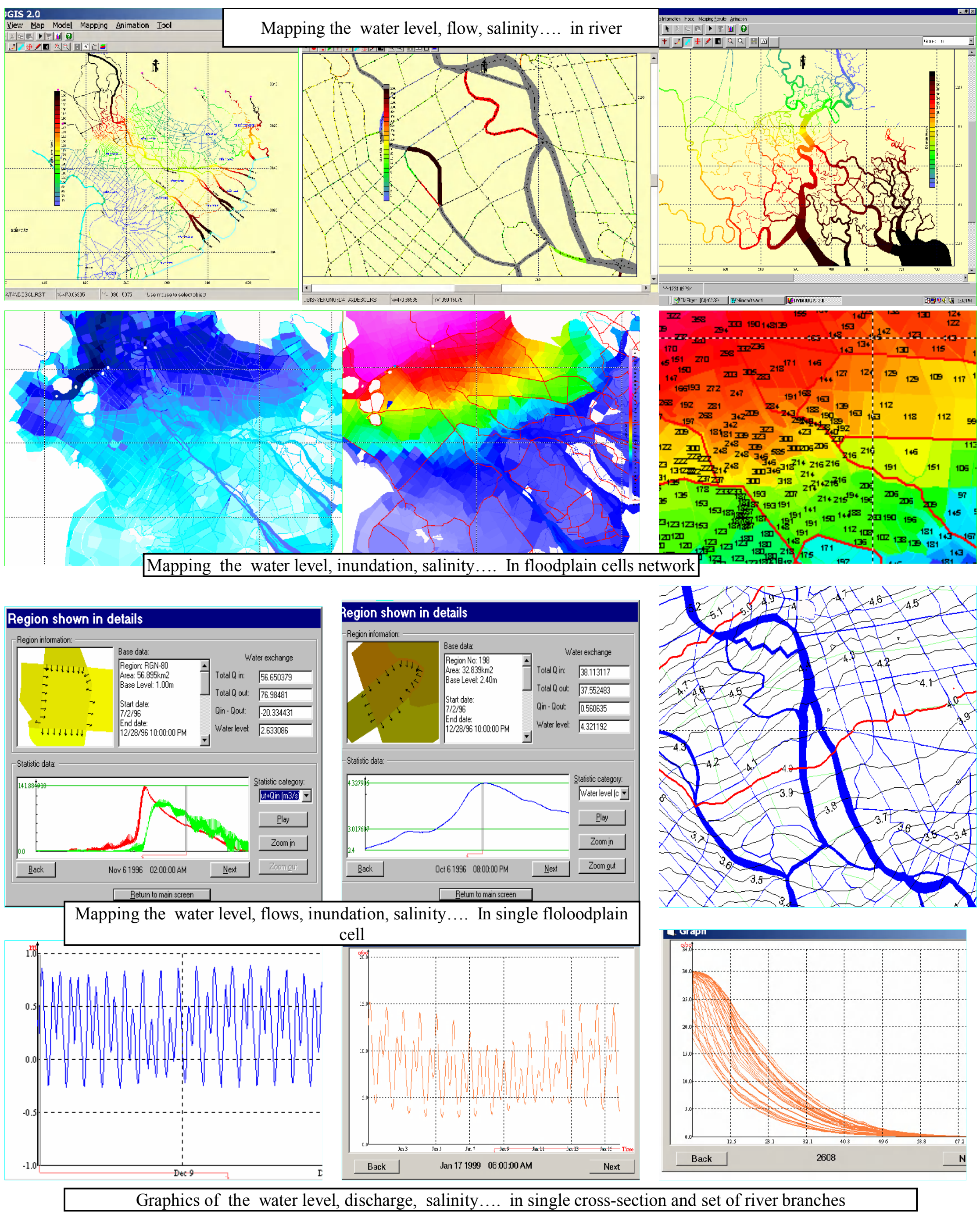



The other important tools are boxes as editable tables included functional buttons as following: importing/exporting GIS data from/to different standards (MapInf, ArcInfo, ArcGis, Arcview, Bimap pictures, JPG picture, Gif Pictue, Surface..) to **HydroGis** format, transforming data, computing needed characteristic, coordinate projection transform, cut, copy map or objects or database, building colour scale, visualization properties…

## Mapping and graphical tools

Here are some types of mapping tools of **HydroGis**. All of data will be presented in GIS of vector style and allowed to overlay many layers. Some of products of **HydroGis** mapping tools are following:

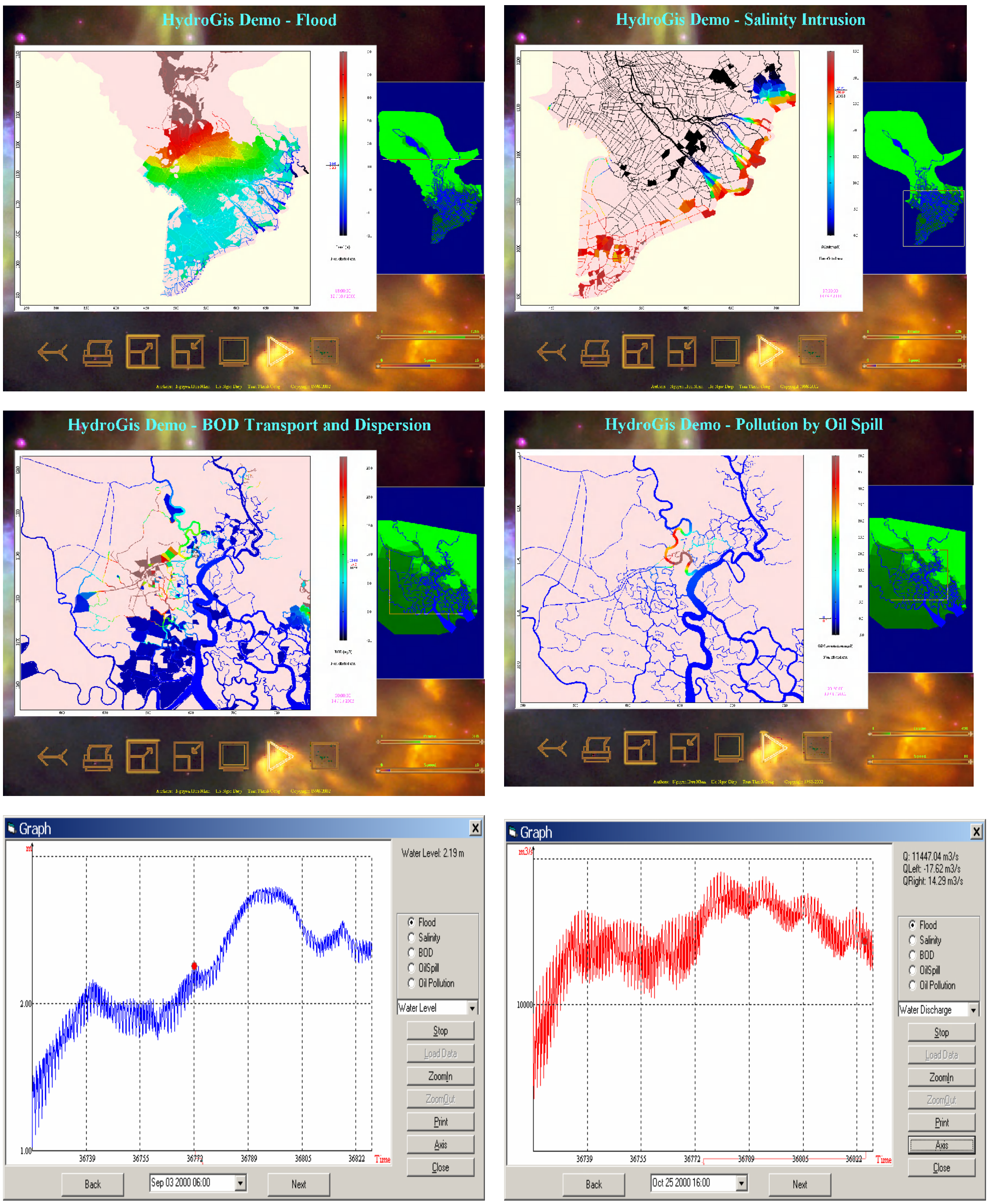
Figure 6. Set of Mapping and graphical tools of **HydroGis**



## Animation tools

The animation tool is very power technology of visualization of **HydroGis** for mining, analyzing, exporting and printing simulated and predicted results. The Main and navigate windows of this tool are for modeled data of flood, salinity instrusion, BOD transport and weatering of spilled oils as below:

Figure 7. Set of animation and data mining tools of **HydroGis**



## 5. Testing and Verifying hydrodynamic engine of HydroGis

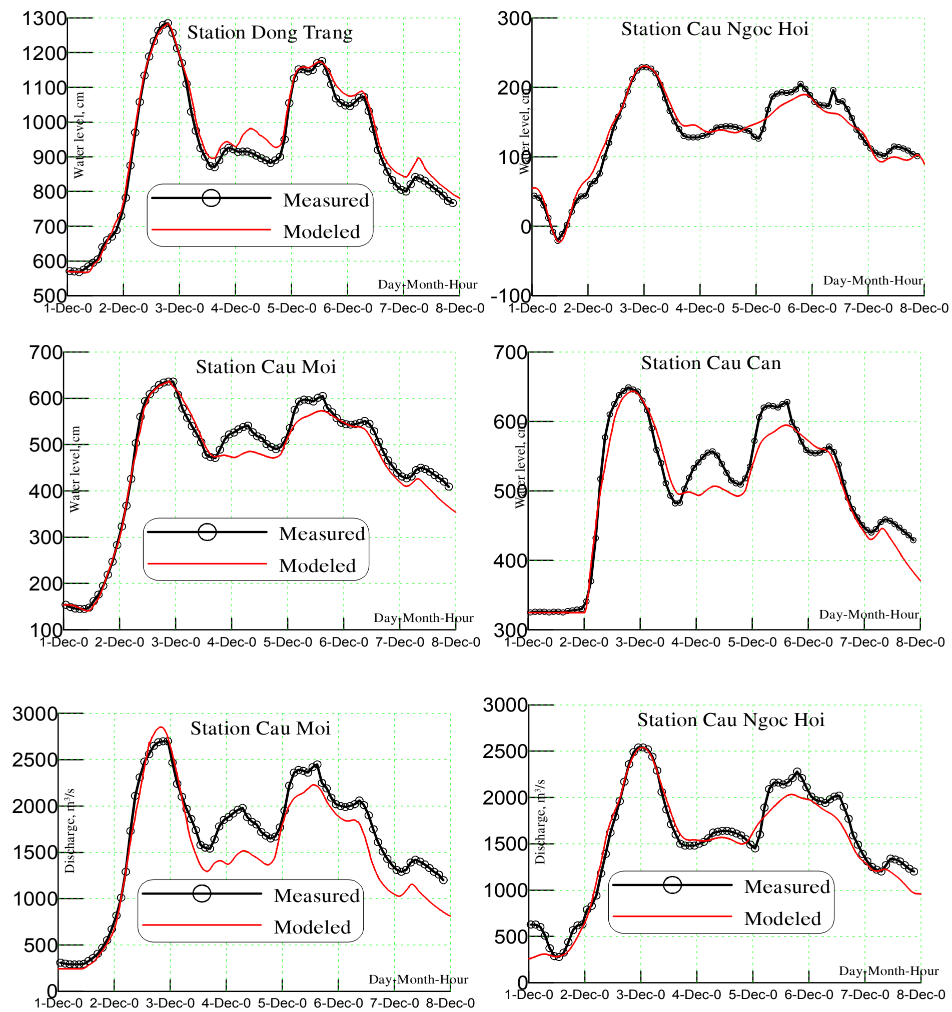
All components of hydrodynamic numerical models in **HydroGis** had been tested on 12 scenarios recommended by European hydraulic experimental labs including analytic tests, numerical stable and approximation, sensitivity of numerical algorithms and numerical conservation.

In addition, the model also had been tested by comparison between model results with sample measured data in 4 typical river deltas:

- River delta with major influence of tidal oscillate in Thi Vai river (Vung Tau city);
- River delta with minor influence of tide in Cai river (Nha Trang city)
- River delta with major influence of both tide and upstream stream in Mekong river (south Viet Nam)
- River delta with high density of man-made infrastructure in Sai Gon-Dong Nai river (south Viet Nam).

The full documentation on these model tests had been presented in [12]. Some of comparison between model and measured data are showing below.

Figure 8. The Comparison of measured and modeled data
in Cai River, Nha Trang City



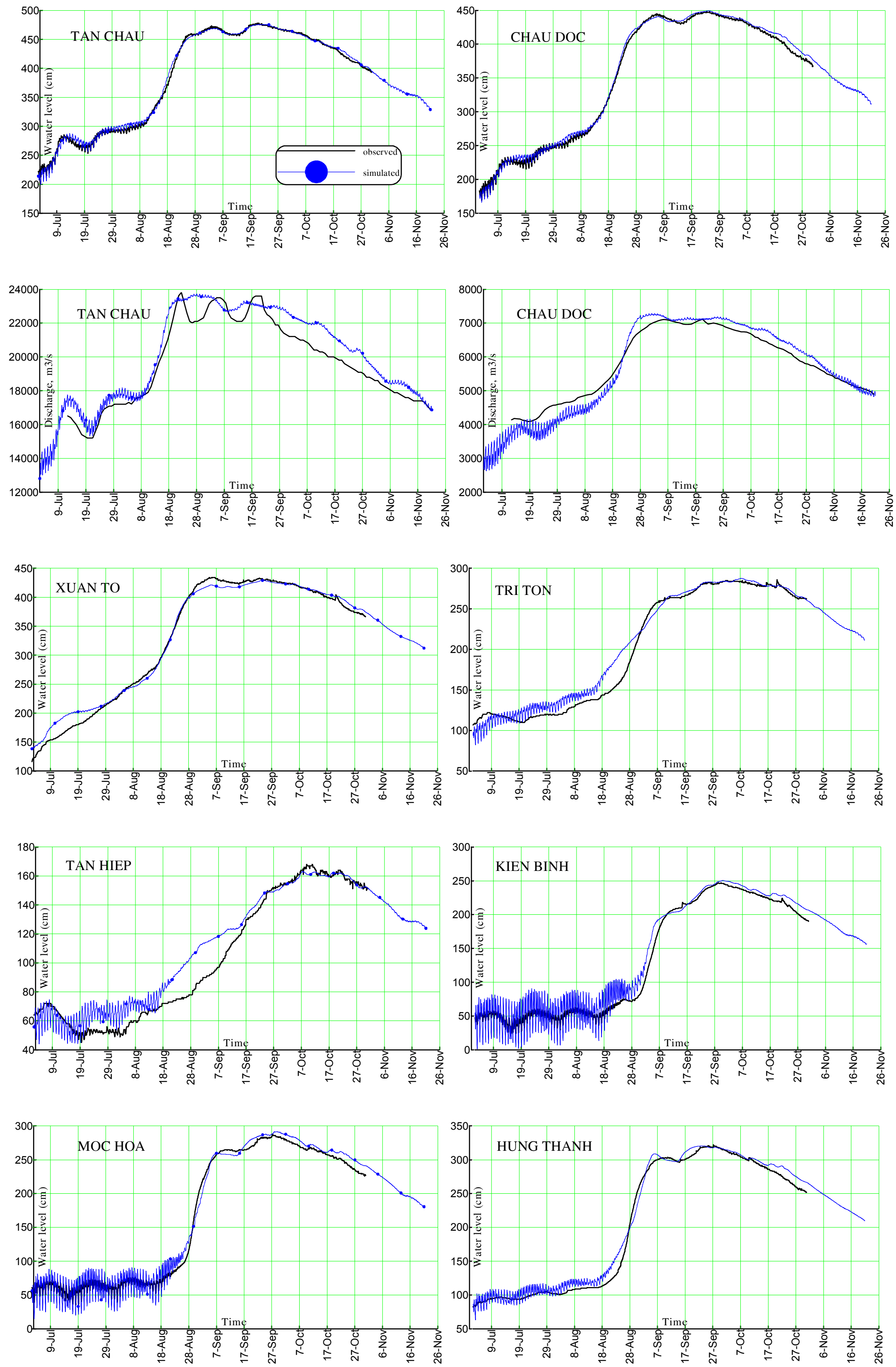



Figure 9. Comparison between **HydroGis** result and observed data in Mekong river delta in 2001

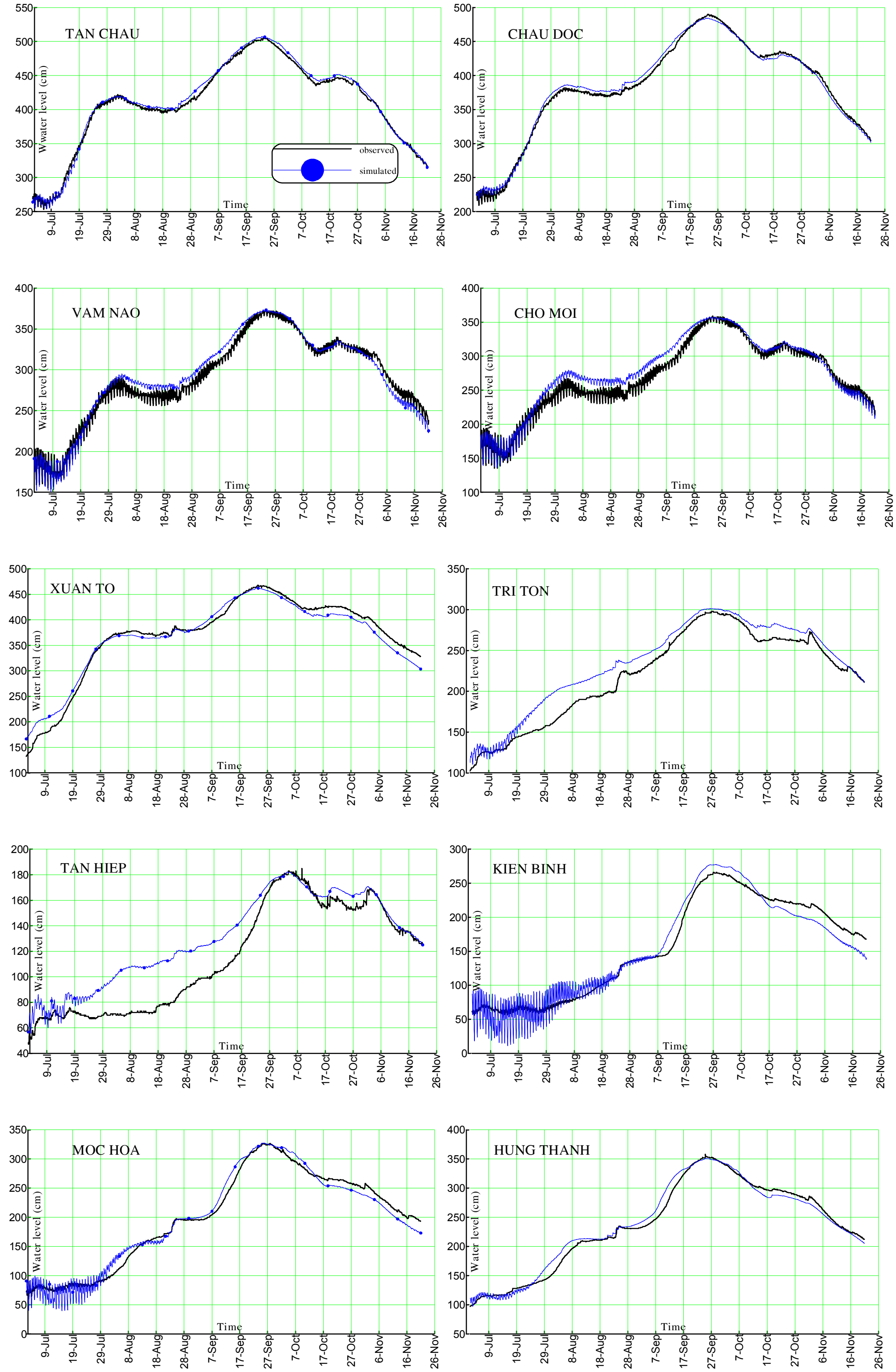



Figure 10. Comparison between **HydroGis** result and observed data in Mekong river delta in 2000

## 6. Summary on HydroGis Model

1. The **HydroGis** is a system linked by mass transport and hydrodynamics models in river basin and special GIS models. These models are operated on the databases, knowledge-bases of Viet Nam.
2. **HydroGis** is power and full packaged software installing and operating on desktop/laptop PC Pentium II or higher.
3. The main applied purposes of **HydroGis** are modeling flood, salinity intrusion and spreading of wastewater in low river delta
4. **HydroGis** is easy, friendly and effective for both operated users and researchers.
5. **The input databases in GIS** of all parameters include**:**

- Basemaps of river delta basin (landuse, soil, administration, road, hydro-meteorological network, water bodies, population, industry, transport…);
- Geometry and topography of river network, flood plan cell network and infrastructural constructions, which control all hydrodynamic processes and mass transport in low river delta basin;
- Hydrology, hydro-geology and meteorology (rainfall, wind, temperature, evaporation, infiltration, flow from underground water, flow from upstream boundaries; tide, storm surge, wind, salinity…from open sea);
- Waste sources of pollutants from domestic area, industrial zones and harbours;
- Oil spill and related data of weather and bio-physic-chemical properties of spelled oil.

6. **The output databases** in GIS of all parameters include:

- Simulated/predicted water level, discharge, velocity, deep of inundation and water balances, mass balance, salinity, substance concentrations of any cell and cross-section.
- Simulated/predicted data on spreading and decay of organic pollutant (BOD5) wasted from domestic area, industrial zone and harbor places.
- Simulated/predicted data spreading and weathering spilled oil.
- Reported maps, graphics, tables from input databases;
- Reported overlay multilayer maps;
- Reports of integrated maps on statistical characteristics (integrated flow, maximum, minimum, average) on water level, discharge, velocity, deep of inundation and water balances, mass balance, salinity, substance concentrations) for any months and full computing time period ;
- Animations of flood and tidal propagation, salinity intrusion, water balance for every cell, cross-section, river branch/group river branches.

7. **The functions** of **HydroGis** are***:***

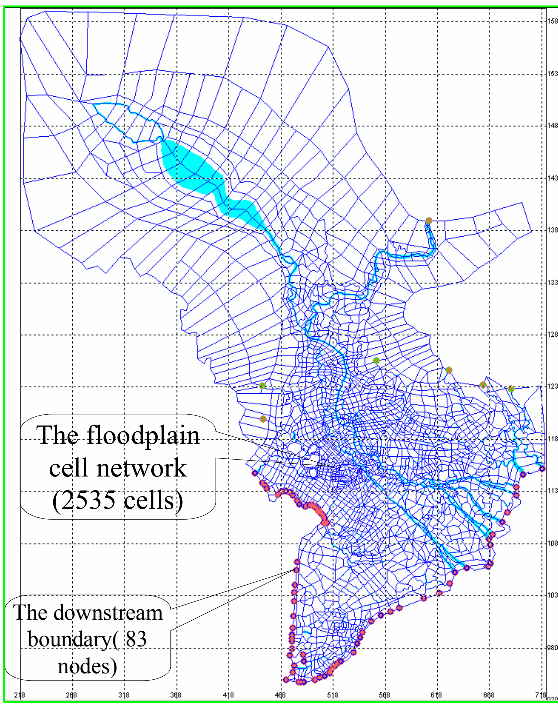
- Modelling/predicting flood, salinity intrusion, spreading waste water and oil spill in river delta basin;
- Management hydro-meteorological database, hydrological regime, infrastructure, water quality for low river delta basin;
- Planning *engineering developments, urbanization* and environmental protection for low river delta.

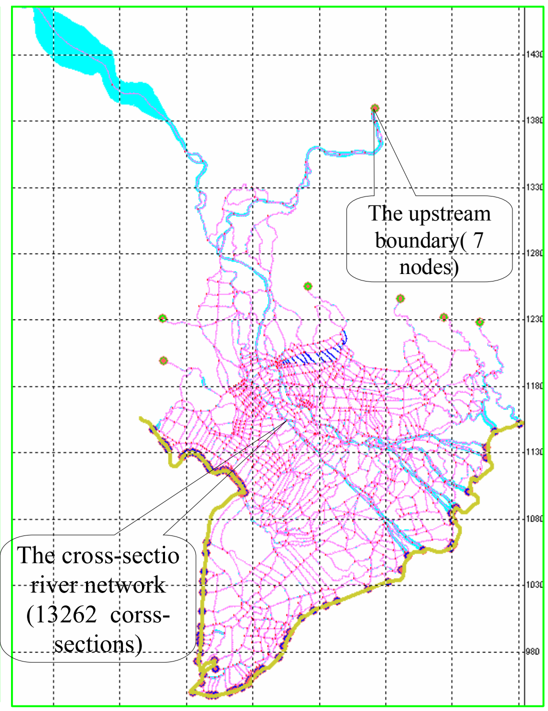
## 7. Some applications

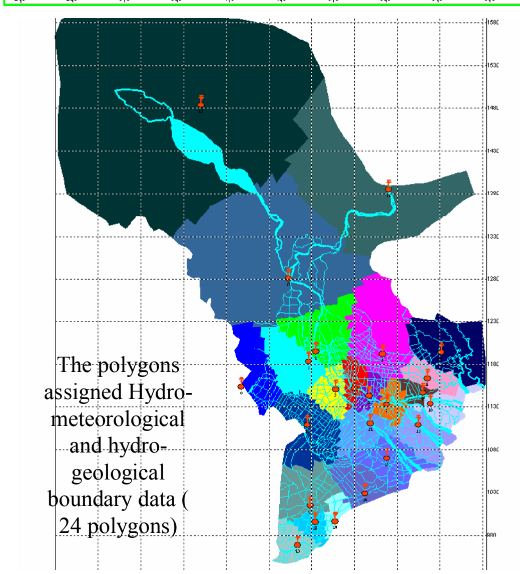
The model **HydroGis** had wide application for modeling/predicting flood and salinity intrusion **in Mekong river delta** in Viet Nam from 1997 to present time [1-4, 7-21]. The model space includes full lower Mekong river delta downstream Kratie and Tole Sap lake showed in following figures. The summary report on digital hard boundary database approximated model area is showed on right. There are 13262 cross-section, 2535 floodplain cells, 466 infrastructural constructions, 82 downstream boundaries, 7 upstream boundaries, 1194 internal nodes. It is very big hydraulic mesh in lower Mekong River delta.

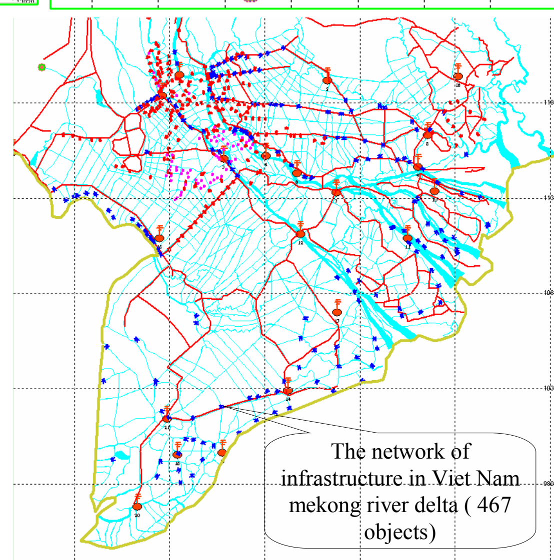
Summaries

| Item | Value |
|---|---|
| Working database | pa5_th8.rst |
| Minx | 218.0 |
| Maxx | 723.0 |
| Miny | 930.0 |
| Maxy | 1593.0 |
| Number of Branches | 2006 |
| Number of Cross-sections | 13262 |
| Number of Regions | 2535 |
| Number of Nodes | 1194 |
| Number of Inflow Boundaries | 7 |
| Number of Water Boundaries | 82 |
| Number of Hydro-Meteorological ! | 24 |
| Number of Geo-Points | 12238 |
| Number of Output-Points | 55 |
| Number of Sewer-Points | 467 |



The special points are:

– The full database of storm surge and harmonic constants of 67 tidal waves at 83 river mouths and with needed accuracy for Mekong river had been set up. It stimulates uses for the model and database in forecasting activity;

– There is only one open boundary in Kratie needed in discharge data which are simply computed by Q(h) rating curve, because all river flows to Tole Sap are located inside floodplain cell network. This provides a minimization in updating hydrological input data. It means, the model mesh is optimal for operational use;

In practice, **HydroGis** with this hydraulic mesh has been applied to simulate and forecast floods and salinity intrusion since 2000 up to now. The details are presented in [1-4,7-21]. Some results are giving on figure 11, 12.

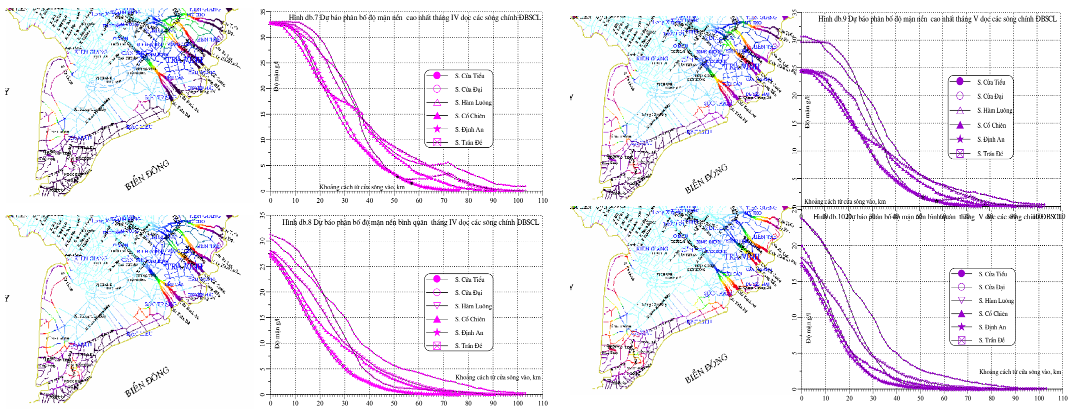
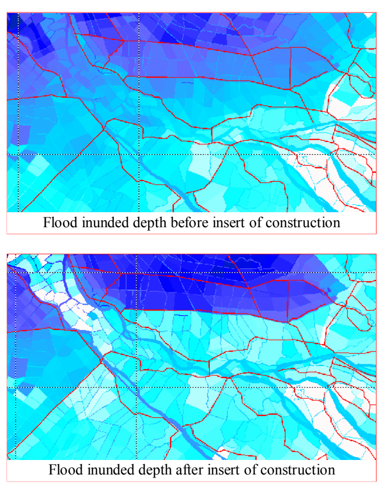


Figure 11. Predictied backround salinity in mekong delta in april anf May of 2004 year by **HydroGis**



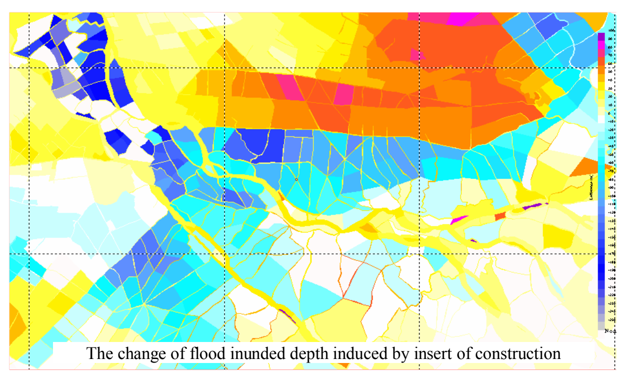




Figure 12. Predicting impact of one scenario of infrastructural development in Mekong river delta on maximal inundation

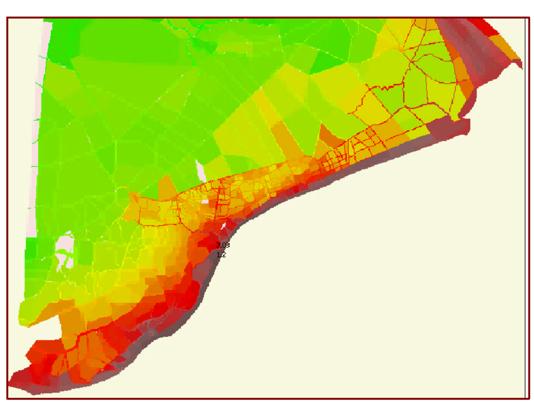


Figure 13. Modelling the flood inundation induced by storm surge in coastal zone of south Viet nam (Storm Linda, 1997)

The **HydroGis** also has wide application to study flood, tide, oil spill, salinity intrusion in Saigon-Dongnai river delta too. Here we have built hydraulic mesh finer than Mekong river delta. There are 9881 cross-section, 1730 cells, 85 waste sources and 5 upstream boundaries, 565 internal nodes. It is very fine hydraulic mesh.

The special features of hydraulic mesh and database for Saigon-Dongnai river delta are:

- Large databases of waste sources from Ho Chi Minh City, Bien Hoa City and many industrial areas had been made. It gives a chance for modeling/predicting/managing the water quality in river basin. It is very actual problems;
- The full database of storm surge and harmonic constants of 67 tidal waves at 2 river mouths and with high accuracy had been set up. It is good for forecast.

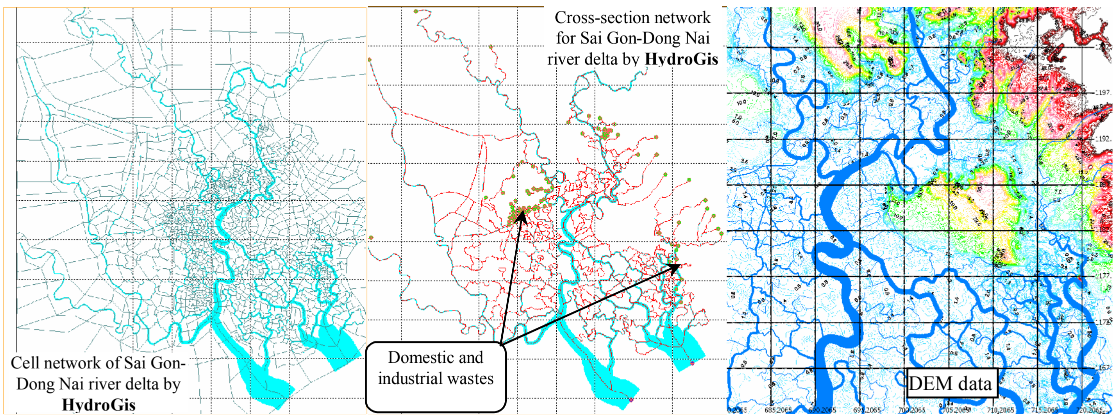
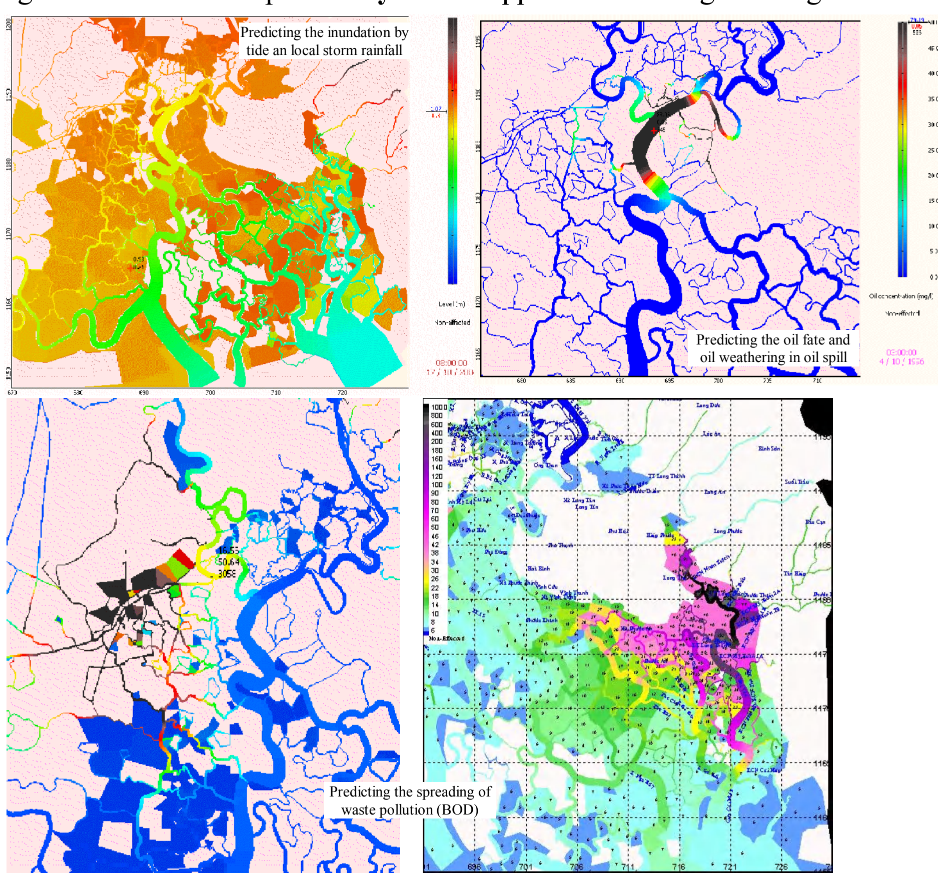



Figure 14. Some examples of **HydroGis** application in Saigon-Dongnai river delta



The **HydroGis** had applied for Cai river Nha Trang City of 3 projects: (1) Building flood maps; (2) Predicting impact of infrastructure development in lower basin; (3) computing water balances of flood of different frequency. The hydraulic mesh of Cai river delta as below picture. Here are 2583 cross-section, 1326 cells, 17 upstream boundaries. It is very fine hydraulic mesh .

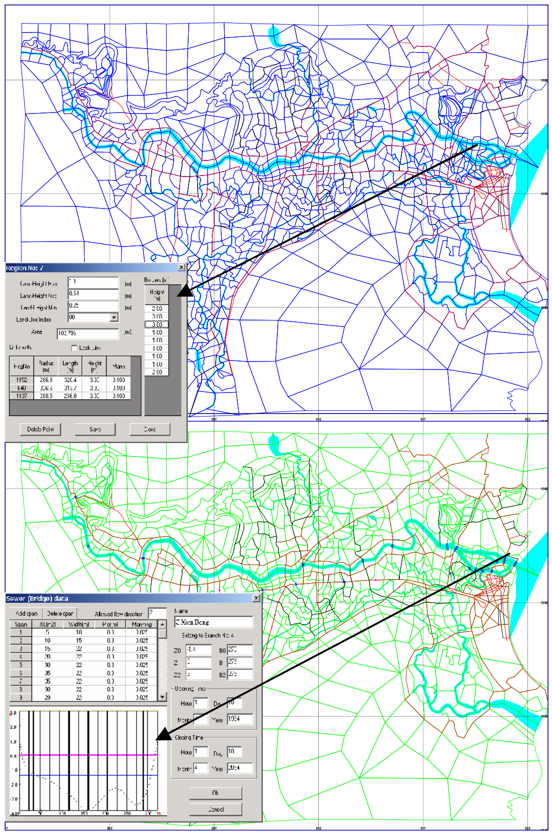



Figure 15. The floodplain cell network of Cai river delta

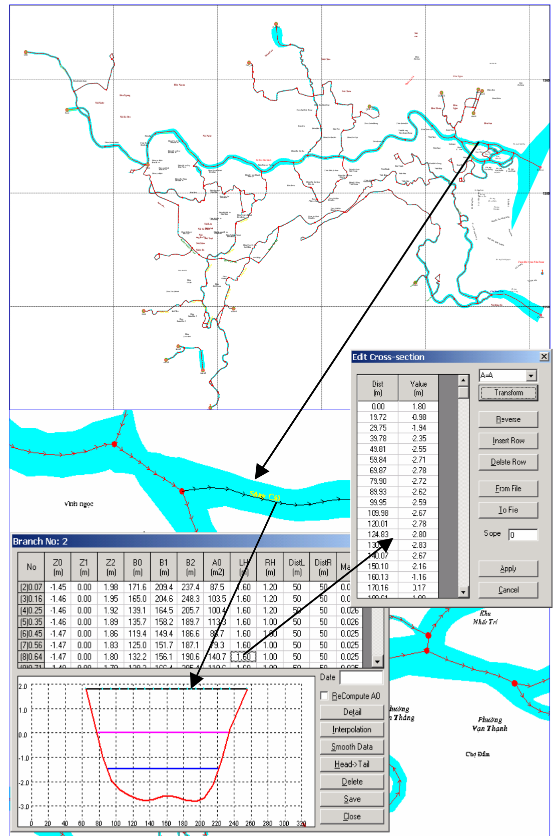



Figure 16. Network of cross-sections

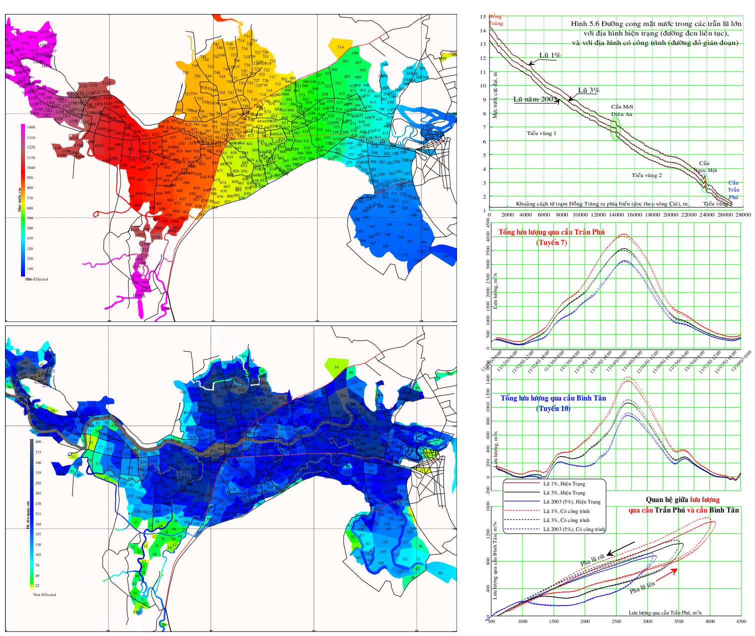


Figure 17. Some hydroGis results of flood modeling in Cai river basin

The **HydroGis** also was used to predict impact of infrastructural works on flooding of Dinh river in Khanh Hoa province. The river and cell networks approximated the Dinh river basin are below. This is small computation hydraulic mesh with 2563 cross-section, 1326 cells.

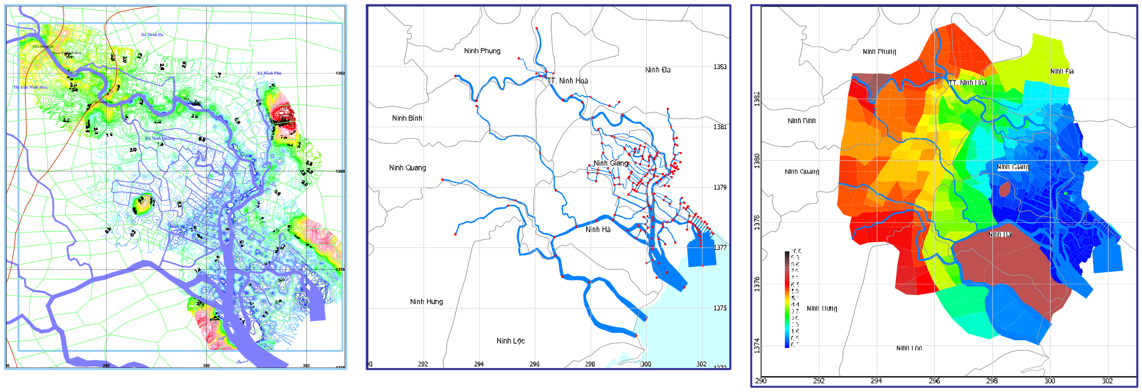



Figure 18. The set of hard boundary database for flood studies by HydroGis model in Dinh river basin

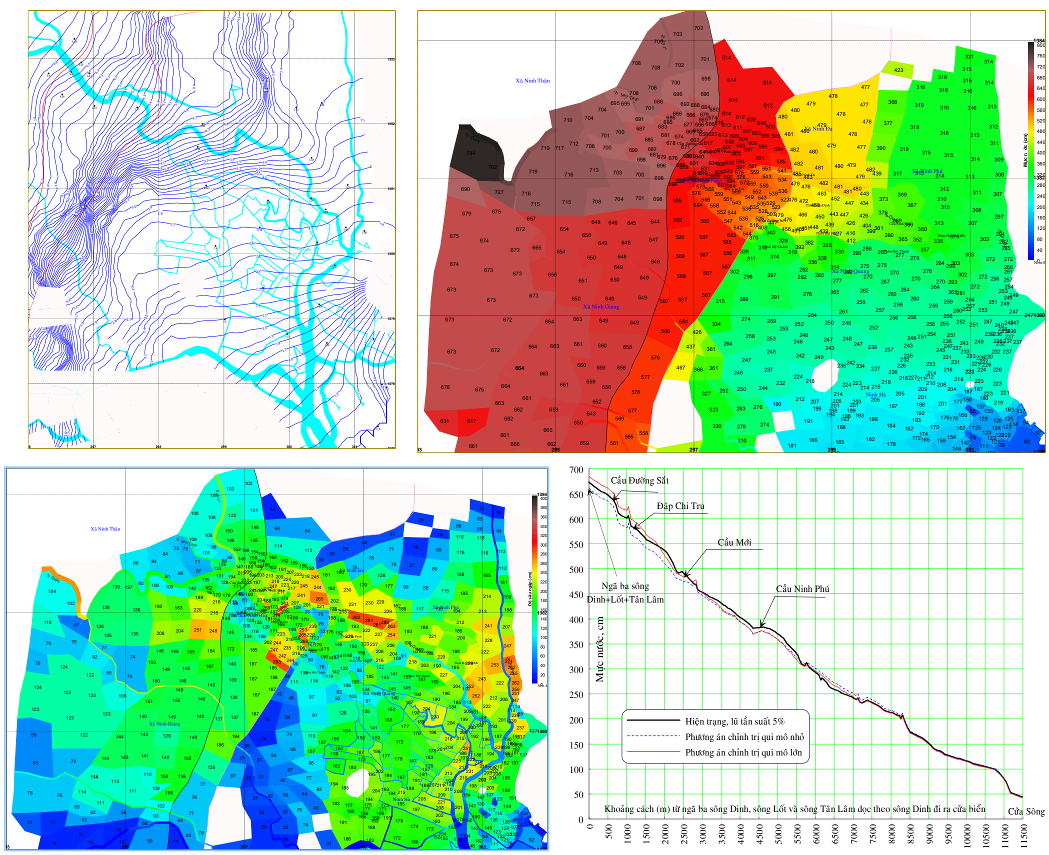



Figure 18 Some model results of flooding in Dinh river basin

The **HydroGis** also is planning to apply for predicting floods of Red river delta. The river and cell networks approximated by 3417 cross-sections, 1322 floodplain cells.

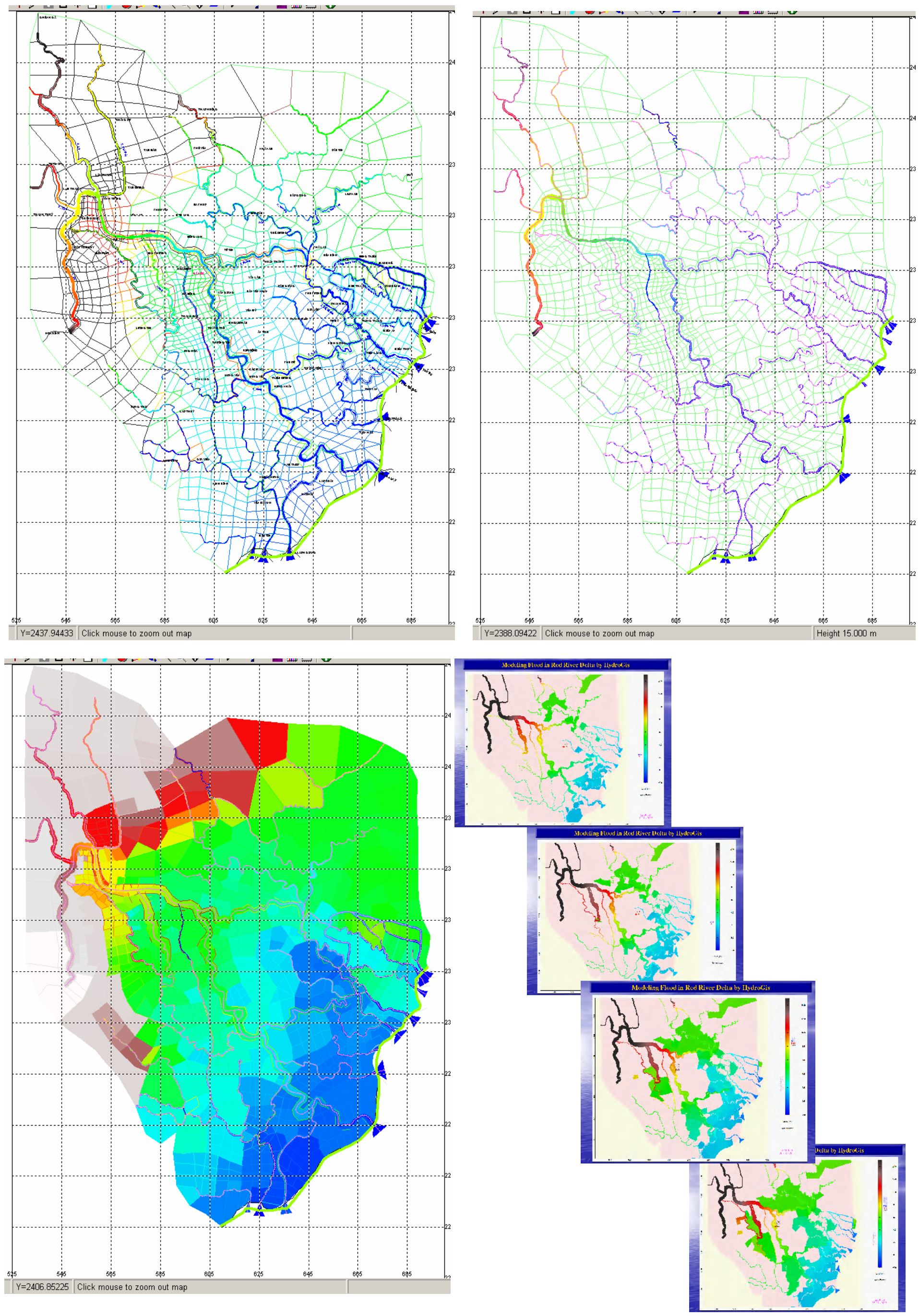


Figure 19 Prepared databases and some simulated flood maps
Red Rver Delta

The HydroGis was used for predicting combined The Combined impact on flooding Vietnam's Mekong River Delta of Local man-made structures, sea level rise, and dam upstream in river catchmeent [1,  2, 3, 4, 5, 6].

The newest application of HydroGis was made for HCMC and  Surrounding Provinces Project "Planning for inundation mitigation for Ho Chi Minh city area" (2008) and ADB Project "Ho Chi Minh City Adaptation to Climate Change" by ICEM, Australia (2009). The HydroGis included database is using as tool for simulation/prediction of inundation induced by alone/combined effect of upstream flows, tide, storm surge and sea level rise with topography and Infrastructure in present status and in planned for inundation mitigation in future. There some outputs of this study as following.

Fig 21. The Map of Maximal water level in scenario: Uptream flows in 2000 with havy storm rainfall and maximal tidal amplitude at river mouths

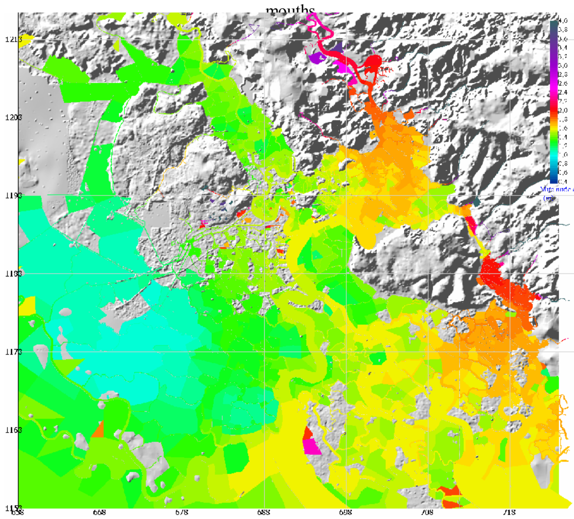


Fig 22. The map of maximal inundation in scenario: Uptream flows in 2000 with havy storm rainfall and maximal tidal amplitude at river

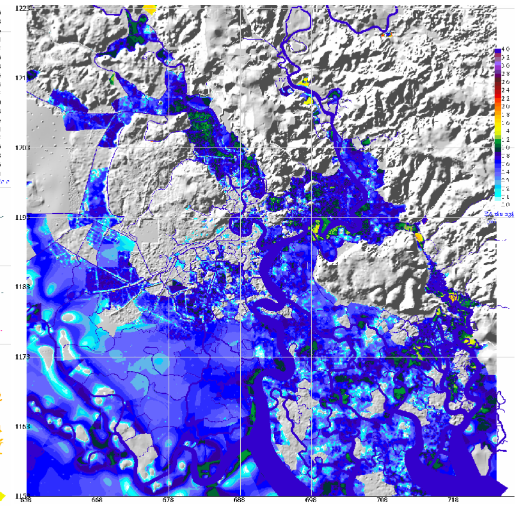


Fig 24. The map of maximal water level in scenario: Uptream flows in 2000 with maximal tidal amplitude and extreme storm surge at river

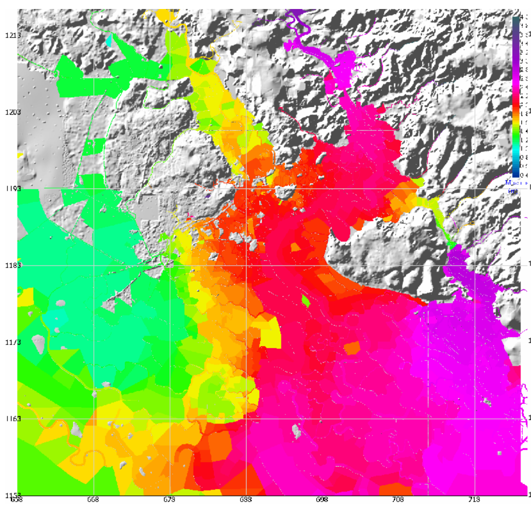


Fig 25. The map of maximal inundation in scenario: Uptream flows in 2000 with maximal tidal amplitude and extreme storm surge at river

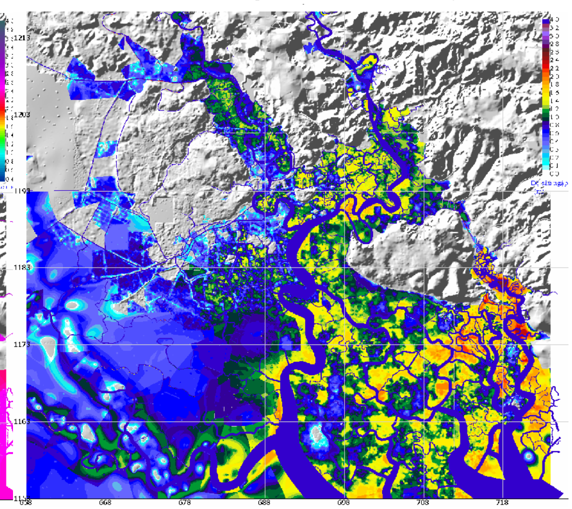


Fig 26. The map of maximal water level in scenario: Uptream flows in 2000 with maximal tidal amplitude, extreme storm surge and sea level rise 70cm

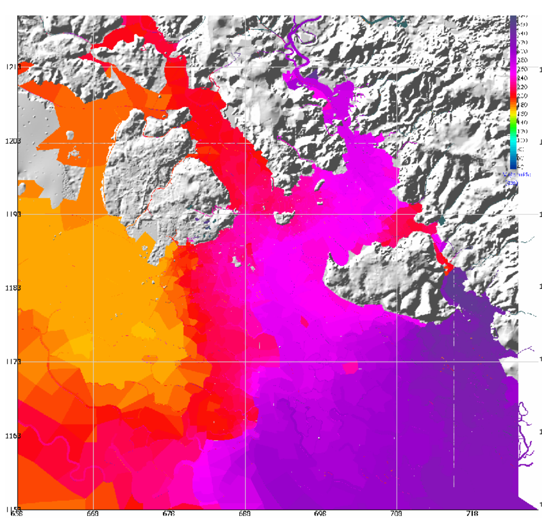
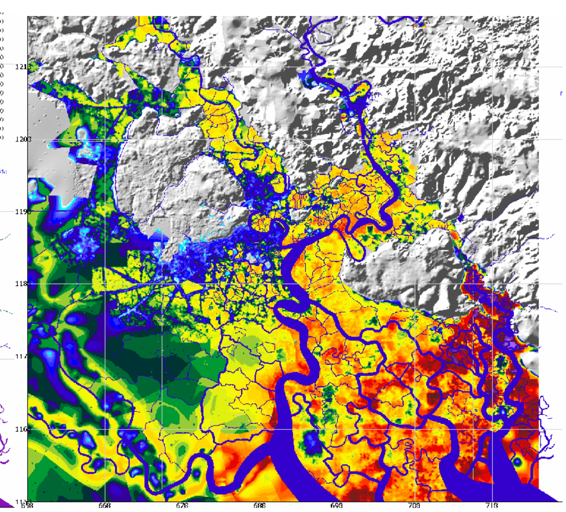


Fig 27. The map of maximal inundation in scenario: Uptream flows in 2000 with maximal tidal amplitude, extreme storm surge and sea level rise 70cm



## 8. Conclusion

The **HydroGis** has the necessary properties in both types of applications: simulating and forecasting hydrological and environmental processes in river delta as assistant operational tool. However it also needs in advanced development to become truly forecasting tool.

### Reference

1. ***Le Thi Viet Hoa (2007).*** *Hydrological effects of local man made control structures in Mekong River Delta in Vietnam.* The Doctoral Thesis. University of Tokyo. 2007. 245pp.
2. ***Le Thi Viet Hoa, Nyuyen Huu Nhan, Wolanski Eric,*****Haruyama Shigeko, Nguyen Huu Nhan, Tran Thanh Cong (2007).** *The Combined impact on flooding Vietnam's Mekong River Delta of Local man-made structures, sea level rise, and dam upstream in river catchment. Coastal and shelf Sciences. Vol. 71 (1-2): 110-116.*
3. **Le Thi Viet Hoa, Haruyama Shigeko, Nguyen Huu Nhan, Tran Thanh Cong (2008)**. *Infrastructure effect on floods in Mekong Delta in Viet Nam. J. Hydrological Processes 22, 1359-1372.*
4. **Le Thi Viet Hoa, Haruyama Shigeko, Nguyen Huu Nhan, Tran Thanh Cong** (2004). "*Simulation and assessment of flood 2000 in lower Mekong river using hydraulic model* **HydroGis**", Proc. of the General meeting of the Association of Japanese Geographers, No 66, 2004, p.75.
5. **Le Thi Viet Hoa, Haruyama Shigeko, Nguyen Huu Nhan, Tran Thanh Cong** (2005). "*Using* **HydroGis** *model to simulate flood flow in Mekong river delta in Vietnam*", Mekong river Symposium, Yamanashi University, 2005
6. **Le Thi Viet Hoa, Haruyama Shigeko, Nguyen Huu Nhan, Tran Thanh Cong** (2005). "*Study of 2001 flood using numerical model in the Mekong river delta, Vietnam*", Proc. of International Symposium on Floods in coastal cities under climate change conditions, AIT, Thailand, 23-25 June, 2005, 6pp
7. **Nguyen Huu Nhan (2006)**. *The environment in Ho Chi Minh City Harbours. Chapter 17, pp 261-291 In book "The environment in Asia Pacific Harbours" Ed. by E. Wolanski, Springer, Dordrecht, Netherlands, 497 pp.*
8. **Nguyen Huu Nhan and another (2000)**. *The applied assistant software HydroGis for modelling flood and mass transport in low river delta. International European-Asian Workshop "Ecosystem & Flood", Proceedings, Ha Noi, Vietnam, 329-350.*
9. **Nguyen Huu Nhan, Tran Thanh Cong, Ho Ngoc Diep (2003).** *Development* **HydroGis** *model for forecasting flood and salinity intrusion in low Mekong delta*. Report of Project in Ministry of Natural Resources and Environment, Hydro-Meteorological Service of Viet Nam 1999-2001;
10. **Nguyen Huu Nhan, Tran Thanh Cong (2004).** *Developing WQMA (Water quality Modelling Assistant) for Saigon-Dongnai River basin*. Report of provincial project in HCM City.
11. **Nguyen Huu Nhan, Le Thi Viet Hoa, Luong Xuan Dai, Tran Thanh Cong (2005).** *Studying Impact engineering infrastucture in Cai river in Khanh Hoa Province*. Report of provincial project.
12. **Nguyen Huu Nhan, Le Thi Viet Hoa, Luong Xuan Dai, Tran Thanh Cong (2005).** *Studying Impact engineering infrastucture in Dinh river in Khanh Hoa Province*. Report of provincial project.
13. **Nguyen Huu Nhan, Le Thi Viet Hoa, Luong Xuan Dai Tran Thanh Cong (2005).** *Studying impacts of Vamcong Bridge in Hau river to Mekong River Delta*. Report of TEDI Ha Noi.

14. **Nguyen Huu Nhan (2003).** *The results of tests and verifications of* **HydroGis** *model.* Hydro-Meteorological Service of Viet Nam project.
15. **Nguyen Huu Nhan, Tran Thanh Cong (2001).** *Developing* **FloodMap** *model of predicting of Flooded inundation in Cai River basin in Khanh Hoa Province*. Report of provincial project.
16. **Nguyen Huu Nhan, Ho Ngoc Diep** (1998). *The* **HydroGis** *for dynamic flood mapping*. Journal of Meteorology and Hydrology 1(461)**. Ha Noi,**
17. **Nguyen Huu Nhan, Tran Thanh Cong** (2000). *The assessment of salinity intrusion and BOD transport induced by re-opening waterway in Soairap river in Saigon-Dongnai river network*. HCM city.
18. **Nguyen Huu Nhan, Tran Thanh Cong** (1999). *The modeling transport and dispersion wastewater from Hp Chi Minh city in Saigon-Dongnai river network and assessing effects of some minimized scenarios*. Consulate report by contact with the Institute of Geography. HCM city.
19. **Nguyen Huu Nhan, Pham van Duc, Nguyen Ngoc Vinh, Tran Thanh Cong** (2000). *Modelling organic water pollution in Ho Chi Minh City's canals and hydrologic coses obstrucling the release processes of wastewater*. Journal of Meteorology and Hydrology 5(473)**. Ha Noi,**.
20. **Nguyen Huu Nhan (1996).** *The software MKGMLVL***.** Project of forecasting of water level in Mekong river mouths phase III . MRC, Bangkok
21. **Nguyen Huu Nhan(2001).** *Studies of water and mass balances in South of HCM City*. Report of project in People's Commission of HCM city.
22. **Nguyen Huu Nhan(2000).** Testing the standards for outputting wastewater to Thi Vai River. Report of MOSTE of Viet Nam 1999 Project;
23. **Nguyen Huu Nhan, Ho Ngoc Diep** (1998). *Studies of spreading of pollutants on Tham Luong canals of Sai Gon River basin.* Report of Project in National Centre of Natural Sciences and Technology of Viet Name 1999-2000).
24. **Nguyen Sinh Huy, Nguyen Huu Nhan** (1998). *The application of* **HydroGis** *to research flood in Mekong Delta and assessment of effects of some flood controls scenarios*. National project. HCM city.
25. **SOGREAH** (1972). *Les modeles mathematiques du delta Mekong.* Publ. de I'UNESCO, Paris.
26. **Wolanski E, Nguyen Huu Nhan, Spagnol S.** (1998). *Fine sediment dynamics in the Mekong River estuary in the dry season*. J Coastal Research. Vol.14. No.2.
27. ***Wolanski E., Nguyen ngoc Huan, Le Trong Dao, Nguyen Huu Nhan*** *(1996). Fine Sediment dynamics in the Mekong River estuary. J. Estuarine Coastal and Shelf Science. No3.*
28. **Wolanski E., Nguyen Huu Nhan (2004)**.*Oceanography of Estuary of Mekong River. 113-115 In book "Mega-deltas of Asia -Geological evalution and human impact" Ed. by Chen Z., Saito Y. Goodbred S.L., China Ocean Press, Beijing, 268 pp*