Development of GIS Aid System of Municipal Drainage Network Planning

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Abstract: Geographical Information Systems (GIS) can support a wide range of spatial query and analysis that can be used to support municipal drainage network planning. This paper combines the planning problems of drainage pipe system with the application of the supportive tool GIS and Object Oriented technology. It is structured in three different sections, current condition of municipal drainage pipe system planning in China, a particular design based on integrated computer program to support drainage pipe network planning and how it is used in a municipal storm water pipe system planning project in Beijing.

Key words: drainage pipe systems planning, GIS, hydraulic calculation

1. Introduction

Wastewater and storm water management in urban areas is a highly interrelated procedure covering different spatial scales and various fields of expertise. Design of municipal drainage network plays an essential role in the process of management. Drainage systems are pipe networks designed to carry wastewater and storm water from different sources to an outfall. The sources include residential, industrial, or commercial areas. When gravity flow is not possible, due to topography or other physical obstructions, the wastewater or storm water is pumped to a point of higher elevation and then allowed to flow by gravity (Richard Greene, 1999). In China, the use of traditional design method in calls for high levels of inputs in terms of time and materials, which even sometimes causes damage because of its inherent lack of accuracy. Although programs developed for gravity flow drainage pipe calculation have mushroomed during recent years, they can't display the topology of drainage network in detail or extract attribute data from the project sketch directly for pipe calculation. The design efficiency of drainage networks in complex environments can be enhanced greatly aided by the technology of geographic information system (GIS).

Since the 1970s the field of GIS has evolved into a mature research and application area involving a number of academic fields including Geography, Civil Engineering, Computer Science, Land Use Planning, and Environmental Science (C. Pettit et al., 1998; T. Sarjakoski; Makropoulos et al., 1999; RichardL church, 2002).

Some attempts have been made in using the GIS for the design and analysis of municipal drainage networks. Przybyla and Kiesler (1991) combined the graphic capabilities of GIS with an existing sewer system modeling packages to development the Lexington-Fayette Sewer System. The primary focus of the work by Przybyla and Kiesler (1991) was the assessment of an existing sewer system performance. Other researchers have developed separate models for the generation of the sewer network layout and hydraulic design of pipes in the network (Tekali and Belkaya 1986; Charalambous et al. 1990; Lui and Matthew 1990).

This paper describes the design of GIS aid system for municipal drainage system planning. A component for wastewater and storm water pipes hydraulic calculation has been developed based on Microsoft's Component Object Model (COM). It uses the surface elevations of manhole locations, pipe lengths, relationships between pipe and drainage basin, relationships between pipe and manhole, cover depth of starting pipes and other parameters. The results of the component include sizes, slopes, burial depths for the pipes and the proximate cost of the resulting drainage network. The program uses the spatial analysis capabilities of GIS for the detailed planning of drainage system including pipes and manholes’ locations, the determination of relationship between pipes and drainage basins, profile map generation and data extraction for hydraulic calculation. The result of this research is a GIS-based drainage network design program that provides a handy platform for designers to draw drainage network plant sketch, calculate pipes and adjustment the layout.

2. Development of the design program

2.1. The Framework

Based on the process of municipal drainage network design workflow, a program framework is drawn out as figure 1. Firstly, urban topographic map, street map and other necessary data are loaded and displayed on screen. Secondly, plant sketch of drainage system is done on the base map layers. The relationships between pipes and manholes in the drainage system are maintained automatically by program. Hydraulic calculation is implemented to determinate design parameters of pipes, after current drainage network is verified by program. Thirdly, some pipes are adjusted manually, due to topography or other physical obstructions. Then related burial depth is adjusted on the basis of the relation between pipes. Finally, project maps, hydraulic calculation tables and cost calculation tables are reported automatically by this program.

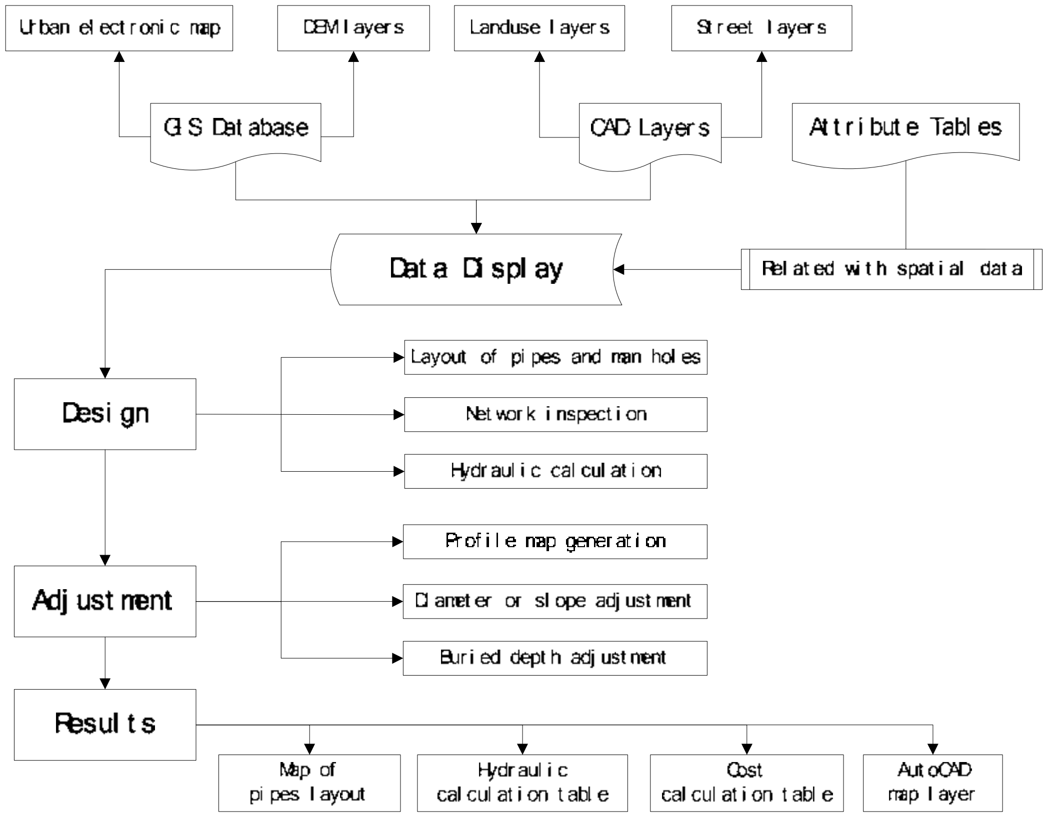

Figure 1. The framework of the design program

2.2. Database design

In this study, calculation parameters database and spatial database are designed to store related data in project. Calculation parameters database is built with Microsoft Access 2000 and includes three tables: storm intensity formula parameters table, Sewer pipe cost table, and storm water pipe cost table; spatial database is constructed in Shapefile data type, including four different map layers: manhole layer, wastewater (or storm water) pipe layer, drainage basin layer, and pipe profile layer. The concrete tables' design of calculation parameters database is described in table 1.

Table 1. Calculation parameters database design

Table Name	Field Name	Field Type	Field's Meaning
Storm intensity formula parameters	City	Text	Record the associated city's name
	A1	Float	Record the value of A_1, c, b, and n in the following formula: $q = \frac{167A_1(1+c\lg P)}{(t+b)^n}$
	B	Float	
	C	Float	
	N	Float	
Sewer pipe cost	Diameter	Text	Record diameter of sewer pipes
	PerCost	Currency	Record unit construction cost
Storm water pipe cost	Diameter	Text	Record diameter of storm water pipes
	PerCost	Currency	Record unit construction cost

Because different project has different map layers, the spatial database is stored in separate directories as ESRI Shapefiles. Files in one project include manhole layer, Drainage pipe layer (wastewater or storm water), drainage basin layer and pipe profile layer. Attribute table's structure of these layers is described in follow table.

Table 2. Spatial map layers' attribute table structure design

Table Name	Field Name	Field Type	Field's Meaning
Manhole	No	Integer	Record manhole's ID
	SurfElev	Float	Record manhole's surface elevation
Drainage basin	Name	Text	Record drainage basin's name
	Area	Float	Record drainage basin's area
	RelPipe	Integer	Record related pipe's ID
	Factor	Float	Record drainage basin's runoff coefficient or wastewater discharge coefficient
Drainage pipe	No	Integer	Record pipe's ID
	Length	Float	Record pipe's real length
	StartP	Integer	Record pipe's upstream manhole's ID
	EndP	Integer	Record pipe's downstream manhole's ID
	Diameter	Text	When pipe is Circle pipe，value equals Diameter When pipe is ditch，value equals Width*Height

	Velocity	Float	Record pipe’s flow velocity
	Slope	Float	Record pipe’s slop
	Quantity	Float	Record pipe’s flow quantity
	FlowArea	Float	Record pipe’s flow area
	StartElev	Float	Record pipe’s upstream bottom elevation
	EndElev	Float	Record pipe’s downstream bottom elevation
Storm water	CollTime	Float	Record pipe’s gathering time of upstream flow
	RainInts	Float	Record pipe’s storm water intensity
Wastewater	Fullness	Float	Record wastewater pipe’s fullness
Pipe profile	No	Integer	Record pipe’s ID
	LabelText	Text	Record pipe profile’s label text

2.3. Network module

Based on Object Oriented technology and the feature of drainage pipe networks, manholes, pipes, drainage basins and the total network are regarded as related classes in Figure 3.

Class manhole is used to describe manholes in drainage pipe network. It has following properties:

1) SHAPEID, used to relate manhole to the shape object in manhole layer;
2) SurfElev, used to record ground elevation of the manhole’s location;
3) StartPoint, used to determinate whether the manhole is a starting point of a branch or not;
4) UpQuanity, used to record wastewater or storm water quantity that passes the manhole;
5) SumFlowTime and SumFlowArea are used to pipe calculation in storm water pipe network planning.

Class DrainageBasin represents drainage basin of each pipe in pipe network. Property BasinArea is designed to store surface area of drainage basin, and property Factor’s value equals runoff coefficient in storm water pipe planning, but it equals wastewater discharge coefficient in wastewater pipe planning.

Class WasteWaterPipe is used to describe pipes in wastewater pipe planning, while class StormWaterPipe is for storm water pipe. Properties StartManHole and EndManHole represent the relationship between pipe and manhole, meanwhile, OwnerBasin links pipe to drainage basin. Design parameters, StartTopElevation, EndTopElevation, Slope, Diameter and Velocity etc., are assigned when method InitialCal or InitialDitchCal is invoked. Method GetQuantity is used to calculate wastewater or storm water quantity that flow through this pipe. After the pipe is adjusted, method AdjustCal or AdjustDitchCal are implemented.

Class PipeNetWork is a collection, which describes the whole wastewater or storm water pipe network. Its property PipeItem's data type is StormWaterPipe or WasteWaterPipe dependent on the value of NetworkType. Method NetWorkCal is used to calculate the pipes at beginning. During the process, pipes are calculated one by one through the direction of gravity flow in them. Private methods FindFirstPipe and FindNextPipe are also reponisble for this process. After pipes in network are adjusted, method AdjustmentPipe is implemented to find pipes that are adjusted and AdjustCal or AdjustDitchCal that are designed in WasteWaterPipe or StormWaterPipe is executed accordingly.

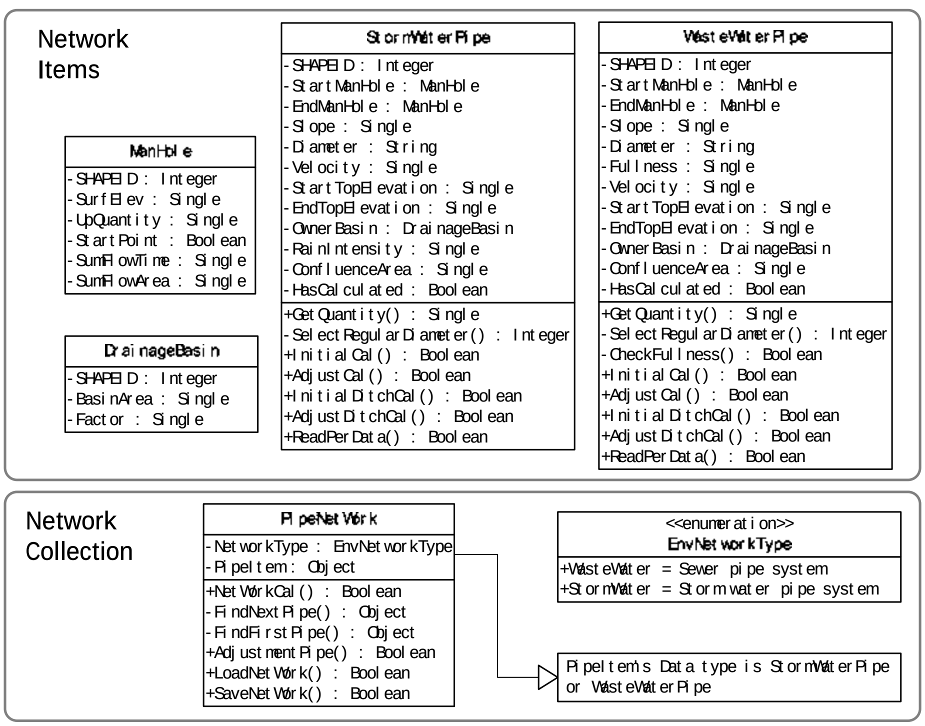

Figure 2. Classes design of drainage network module

2.4. Functional modules

Based on MapObjects control, a popular GIS component released by ESRI (Environmental Systems Research Institute), and ADO (ActiveX Data Objects), a common programming model for any OLE DB data source produced by Microsoft, three functional modules are illustrated in figure 3.

Drawing module is designed to draw plan sketch. Firstly, GIS and CAD data is loaded and displayed. Then, manholes, pipes and drainage basins are drawn and attribute data of them are also set at the same time. Finally, the relationships between them are built automatically or manually.

Calculation module is taken to calculate design parameters of pipes in network. Firstly, hydraulic calculation parameters are initialized for the whole network. Secondly, data validity of map layers and the relationship between them are verified. Some errors are corrected automatically by program; meanwhile, others need intervention from designer. Finally, the network module is invoked, and calculation of pipes is processed one after another from upstream to downstream.

Adjustment module is employed to adjust special pipes in network. Pipe profile map layer is generated by program on the result of network calculation at first. Then pipe adjustment, including diameter, slope and burial depth, is done on the profile layer. Finally, pipes that have been influenced by this adjustment are modified by program according to the upstream and downstream relationship in pipe network.

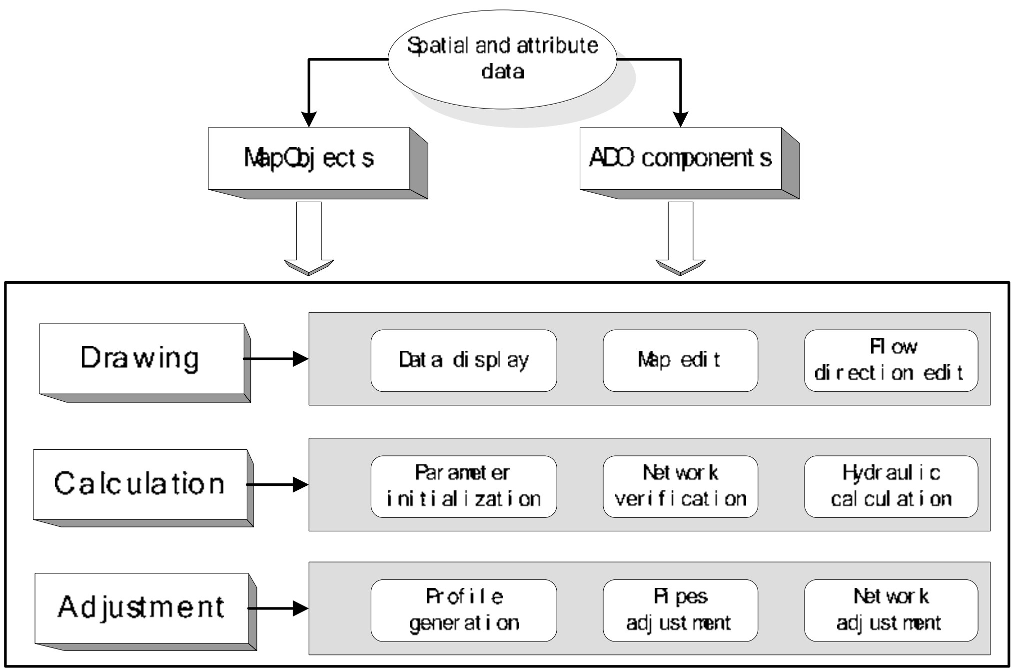

Figure 3. Modules design of the program

3. A case study in Beijing

The program has been successfully applied in storm water pipe systems planning of north area of Shahe satellite city in Beijing.

Urban street planning map in AutoCAD DWG format of this area is loaded and displayed at the beginning. Then pipes and drainage basins are edited directly in this program as figure 4. Manholes are created automatic to link pipes. Meanwhile, the ground elevation of manholes and runoff coefficient of drainage basin are set by designer respective. In order to calculate each pipe's storm water quantity, the relations between pipes and drainage basins need to be built up. Pipes and basins are rendered with ValueMapRenderer, which represents a way of symbolizing features of a map layer by drawing a symbol for each unique data value, relying on GIS components. This method enhances the display effect of the relationships as figure 5.

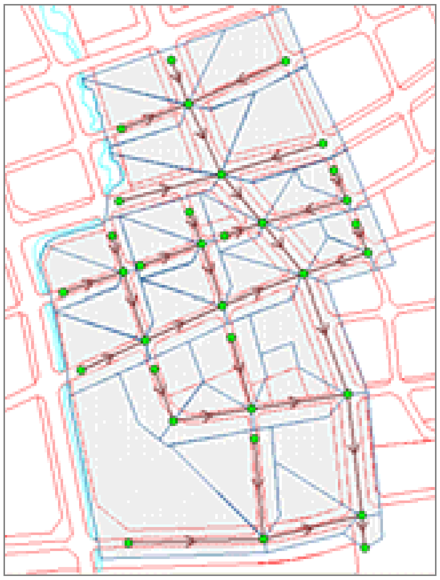

Figure 4. Pipe network's Plant sketch

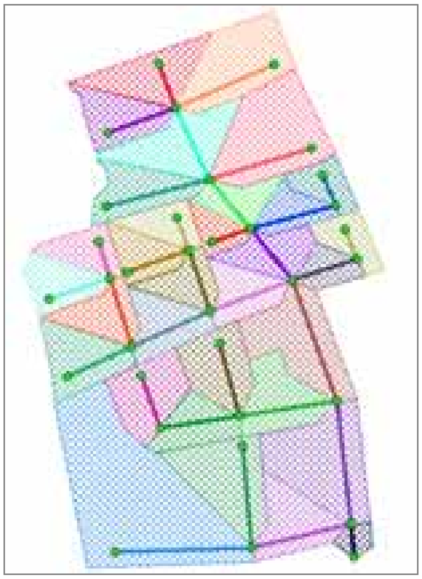

Figure 5. Relations between pipe and basin

Network calculation is invoked after the plan sketch is accomplished. Then pipe profile layer is created as shown in figure 6. The main pipes in network are drawn in upstream and downstream sequence, and then profile of branch pipes is created one by one.

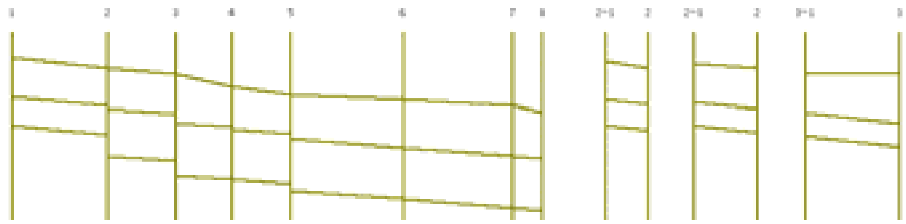

Figure 6. Part of Pipe profile layer

The pipes' detail information is also displayed in profile view. Parameters, such as diameter, length, slope, quantity, velocity, upstream bottom elevation and downstream bottom elevation, are labeled on the map like the following figure.

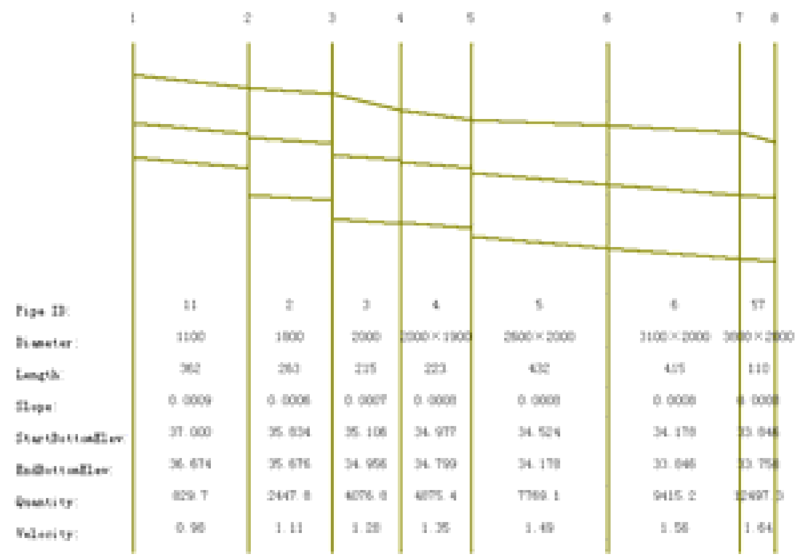

Figure 7. Profile map of main pipes

After some pipes are adjusted in profile view, network adjustment calculation is invoked. Pipes that are influenced by the adjusted pipes are calculated accordingly. And they are displayed with bound line in dashed style as figure 8.

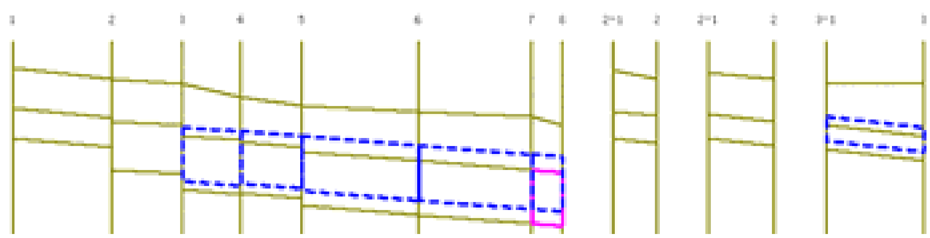

Figure 8. Part of Profile layer adjusted

Finally, cost calculation table and hydraulic calculation table are reported by program like figure 9 and figure 10.

ID	Diameter	UnitCost	PipeCount	PipeLength	PipeCost
1	1100	4320	2	703	303.7
2	1000	3960	4	843	333.8
3	900	3720	4	1123	417.8
4	1800	8560	3	1011	865.4
5	1200	5520	4	1082	597.3
6	2000	13200	2	554	731.3
7	700	3080	1	137	42.2
8	800	3400	6	894	304
9	2000×1900	20000	1	223	446
10	1600	7560	2	612	462.7
11	2600×2000	20000	1	432	864
12	3100×2000	20000	1	415	830
13	3800×2000	20000	1	110	220
SumCost					6418.2

Figure 9. Cost calculation table

PipeID	StartMID	EndMID	Length	DrainA	Runo	SumAr	SumArea	Gather	FlowTi	Rainess	Quantity	Diameter	Slope	Velocity	Capacity	StartBH	EndBH	BHDif
1	1	2	362	7.5	0.55	7.5	4.13	5.00	6.16	201.13	829.7	1100	0.0009	0.96	931.3	37.000	36.674	.326
2	2	3	263	6.3	0.55	23.2	12.76	11.16	3.95	191.83	2447.8	1800	0.0006	1.11	2824.6	35.834	35.676	.158
2-1	2-1	2	242	4.3	0.55	4.3	2.37	5.00	4.29	225.28	532.8	900	0.0011	0.94	598.0	37.000	36.734	.266
2-1	2-1	3	162	5.1	0.55	5.1	2.81	5.00	2.78	250.71	703.2	1000	0.0010	0.97	761.8	37.000	36.838	.162
3-1	3-1	3	356	9.7	0.55	9.7	5.34	5.00	6.05	202.29	1079.2	1200	0.0008	0.98	1108.4	36.400	36.115	.285
3-1	3-1	3	358	4.6	0.55	4.6	2.53	5.00	6.35	199.00	503.5	900	0.0011	0.94	598.0	36.600	36.206	.394
3	3	4	215	2.0	0.55	40.3	22.17	15.11	2.00	183.93	4076.8	2000	0.0007	1.28	4021.2	35.106	34.956	.150
4-1	4-1	4	137	2.0	0.55	2.0	1.1	5.00	2.54	255.55	281.1	700	0.0014	0.90	346.4	36.700	36.508	.192
4-2	4-2	4	294	2.0	0.55	5.4	2.97	6.95	5.21	200.79	596.4	900	0.0011	0.94	598.0	36.300	35.977	.323
4-1	4-1	4-2	111	2.6	0.55	2.6	1.43	5.00	1.95	268.11	383.4	800	0.0013	0.95	477.5	36.700	36.556	.144
4	4	5	223	3.7	0.55	51.4	28.27	17.90	2.75	172.46	4875.4	2000+	0.0008	1.35	5130.0	34.977	34.799	.178
5-2-2	5-2-2	5-2	238	3.6	0.55	10.2	5.61	8.79	4.06	203.38	1141.0	1200	0.0008	0.98	1108.4	36.300	36.109	.191
5	5	6	432	7.9	0.55	96.5	53.08	21.91	4.83	146.38	7769.1	2600+	0.0008	1.49	7748.0	34.524	34.178	.346
5-3-2-1	5-3-2-1	5-3-2	218	3.1	0.55	3.1	1.71	5.00	3.82	232.46	396.3	800	0.0013	0.95	477.5	36.700	36.417	.283
5-3	5-3	5	293	3.7	0.55	32.2	17.71	17.51	4.40	162.02	2869.4	1800	0.0006	1.11	2824.6	34.900	34.724	.176
5-2	5-2	5-3	285	4.2	0.55	19.5	10.73	12.85	4.66	177.54	1904.1	1600	0.0006	1.02	2050.8	35.400	35.229	.171
5-3-2	5-3-2	5-3	220	3.1	0.55	9.0	4.95	8.82	3.74	207.01	1024.7	1200	0.0008	0.98	1108.4	36.000	35.824	.176
5-2-1	5-2-1	5-2-2	128	3.1	0.55	3.1	1.71	5.00	2.25	261.58	446.0	800	0.0013	0.95	477.5	36.900	36.734	.166
5-1	5-1	5-2	105	2.7	0.55	2.7	1.49	5.00	1.84	270.51	401.7	800	0.0013	0.95	477.5	37.300	37.164	.136
5-1	5-1	5-2	240	5.1	0.55	5.1	2.81	5.00	4.12	227.79	639.0	1000	0.0010	0.97	761.8	36.500	36.260	.240
5-2	5-2	5	229	2.3	0.55	5.0	2.75	6.84	4.06	215.56	592.8	900	0.0011	0.94	598.0	36.000	35.748	.252
5-3-1	5-3-1	5-3-2	116	2.8	0.55	2.8	1.54	5.00	2.04	266.15	409.9	800	0.0013	0.95	477.5	37.000	36.849	.151
5-2-2-1	5-2-2-1	5-2-2	216	3.5	0.55	3.5	1.93	5.00	3.79	233.03	449.6	800	0.0013	0.95	477.5	37.000	36.719	.281
6-1	6-1	6-2	254	5.2	0.55	5.2	2.86	5.00	4.36	224.19	641.2	1000	0.0010	0.97	761.8	35.800	35.546	.254
6-2-1	6-2-1	6-2-2	187	5.3	0.55	5.3	2.92	5.00	3.21	242.78	707.7	1000	0.0010	0.97	761.8	36.000	35.813	.187
6	6	7	415	9.3	0.55	125.3	68.92	26.74	4.43	136.62	9415.2	3100+	0.0008	1.56	9672.0	34.178	33.846	.332
6-2	6-2	6	327	5.3	0.55	19.5	10.73	12.79	5.34	172.40	1849.0	1600	0.0006	1.02	2050.8	34.886	34.690	.196
6-2-2	6-2-2	6-2	267	3.7	0.55	9.0	4.95	8.21	4.54	201.23	996.1	1200	0.0008	0.98	1108.4	35.500	35.286	.214
7-2-1	7-2-1	7-2	341	7.3	0.55	7.3	4.02	5.00	5.80	205.26	824.1	1100	0.0009	0.96	931.3	35.500	35.193	.307
7-1	7-1	7-2	455	21.8	0.55	21.8	11.99	5.00	6.93	193.83	2324.0	1800	0.0006	1.11	2824.6	34.700	34.427	.273
7-2	7-2	7	339	5.0	0.55	34.1	18.76	11.83	5.23	177.01	3319.8	2000	0.0005	1.08	3392.5	34.227	34.058	.169
7	7	8	110	1.0	0.55	160.4	88.22	31.20	1.12	141.66	12497.3	3800+	0.0008	1.64	12464.0	33.846	33.758	.088

Figure 10. Hydraulic calculation table

4. Conclusion

Comparing this GIS assistant system with other existing programs, the most advantage is that the relationships between manholes, pipes and drainage basins have been built in project drawing period. Attribute data of the spatial elements can be extracted directly from the project sketch for pipe calculation and adjustment. Shape-drawing functions, such as manhole's moving, manhole's insert and basin's split etc., are expanded specially to meet the function demand of drainage pipe systems planning. Finally, the program has been used in storm water pipe systems planning of north area of Shahe satellite city in Beijing successfully. It helps designer perform municipal drainage pipe network planning more efficiently and takes less time on pipe planning.

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5. Reference

RichardL. Church, Geographical information systems and location science,

Computers & Operations Research, 29 (2002): 541-562
Richard Greene, Newland Agbenowosi, G. V. Loganathan. GIS-based approach to sewer system design. Journal of Surveying Engineering, 1999, 125(1): 36-57
C. Pettit, D. Pullar. An integrated planning tool based upon multiple criteria evaluation of spatial information. Computers, Environment and Urban Systems, 1999, 23(5): 339-357
T. Sarjakoski. Networked GIS for public participation - emphasis on utilizing image data. Computers, Environment and Urban Systems, 1998, 22(4): 381-392
Makropoulos, Butler, Maksimovic. GIS supported evaluation of source control applicability in urban areas. Water Science and Technology. 1999, 39(9): 243-252
Przybyla, J., Kiesler. Extending GIS capabilities for enhanced sewer system modeling. Proc., Conf., Civil Engineering Applications of Remote Sensing and Geographic Information Systems, ASCE, New York, 1991, 105–114.
Lui, G., and Matthew. New approach for optimization of urban drainage systems. J. Envir. Engrg..1990,116(5), 927–944.
Tekeli, S., and Belkaya, H.. Computerized layout generation for sanitary sewers. J. Water Resour. Plng. and Mgmt., 1986, 112(4), 500–515.
Charalambous, C., and Elimam. Heuristic design of sewer networks. J. Envir. Engrg. Div., 1997, 116(3), 1181–1199.

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