Potential Applications To Create Water Supply Decision Model Using Hardy Cross Hydraulic Analysis Method

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ABSTRACT

The water industry is a very complicate task to keep municipal water distribution system in optimal operation. The majority of Taiwan municipal water supply is from rainfall. If we lack the rainfall for extended period of time, we will face problem of water shortage. Therefore, to create a water supply decision model is an important task.

Hardy Cross hydraulic analysis method can be used to perform analysis on water pressure of pipe network. Incorporating method's factor into pipe network analysis calculation can be used to find each water point's possible water supply volume.

This study's purpose is to create a water supply decision model to simulate various water supply volume condition. The decision maker can use this model to study and judge if each area's water supply is sufficient or not. It can provide recommended guideline for decision maker to create water supply policy.

KEY WORDS: Hardy Cross method, Network Analysis Geographic Information Systems

1. INTRODUCTION

The municipal water industry is developing rapidly in recent years. Take water from river developing to build weir, water dam, direct water pipe, water purification facility, the capacity vary from quarter to million cubic meter, water distribution system pipe class, pipe size large and tediously complex, it makes municipal water become both technical and service kind of industrial product. It not only raise people’s standard of living, it also help in improving social welfare.

The municipal water industry is a very complex industry. On one hand it needs to produce safe drinkable water. On the other hand, it needs to provide excellent service to user. The difference between municipal water industry and other industries or service sectors is that year round water supply can’t be interrupted. If you have a water outage, it will cause inconvenience to people’s life and it will impact city function and industrial production.

This study apply geographic information system technology, combine geographic information and pipe network water pressure analysis method, explore how to conform space information in pipe network water pressure analysis process, then feedback the analysis result to pipe network space information, using it as guideline for municipal water pipe network installation and decision for water supply policy.

2. Article Looking Back

The water distribution system costs the greater part in municipal water construction project. Thus, suitable selection of pipe width for water pipe distribution network, service reservoir capacity and location can save construction fee significantly.

So pipe network water pressure analysis play a very important role in municipal water engineering planning design work.

There are four-pipe network analysis methods. (1) Hardy Cross method. (2) Best rank similar pipe length balance method. (3) Newton method. (4) Flow volume balance method.

Generally to simplify water pressure calculation of pipe network analysis, we assume pipe network's water flow is steady flow, thus omit time factor in influencing flow volume. There are two important conditions to achieve water pressure balance in pipe network:

- Flow volume balance condition: In pipe network any two or more water pipe connection point, inflow water volume equal to outflow water volume.
- Water head balance condition: No matter which route the water flow through, the pressure difference between any two points in the network should be the same.

2.1 Pipe network water pressure calculation formula

There are Hazen-Williams Formula and Darcy's Formula in distribute water pipe network calculation, the general formula is

$H = KQ$ 。

K: water pipe's resist block constant, depends on pipe width and how rough the pipe inner surface.

Hazen-Williams Formula : $K = \frac{kL}{C^{1.85} D^{4.87}}$

Darcy's Formula : $K = \frac{8fL}{\pi^2 D^5 g}$

In reality, the pipe line constant "C" used in Hazen-Williams formula's water pipe resist block constant is not constant. It vary depends on pipe width and flow rate variation. Thus if use Hazen-William formula and assume C" as constant, the result won't be accurate. The researcher should use Darcy formula to calculate in order to get more accurate result. But in actual application the error of assuming C" value, as constant and use Hazen-Williams formula won't affect design result significantly, moreover since the formula is simpler, convenience to calculate, thus general engineering application still use Hazen-Williams formula at large.

2.2 Hardy Cross Pipe network water pressure analysis method

Hardy Cross invented this method at 1936. G.M. Fair Howland and Fair Hurst later improved it. It is a trial and error method. Assume every pipe line's flow volume as Q in keeping every connect point inflow/outflow water volume balance condition, use Hazen-Williams formula to calculate pipeline water head lost h, calculate every loop's water head lost close open difference h = 0, then pipeline's water flow already reach balance, if h = 0, then calculate every loop's adjust flow delta Q, use it to correct every pipeline's flow volume, then use every pipeline after adjustment's new flow

volume to repeat calculation several times until delta h less than predetermine acceptable error. This method is use loop water head lose close open difference as water pressure balance calculate condition, thus it is also called water head balance method.

2.3 Network analysis

Geographic information system's network analysis is derived from graph theory. Network is formed from one unit connect point and line segment. If you try to use all possible formula to find the best solution, it will waste a lot of time in calculation and analysis, it is not cost effective, thus the solution for most network problem belong to Heuristic method. The Heuristic method's characteristic is to find solution for one unit or one group (not necessary best solution), then use some mathematical calculation to approach the best solution, but can't guarantee the final solution is the best one.

Geographic information system provides network analysis is for finding solution in rapid time. It normally uses Heuristic method. At present, the most common network analysis methods are Best Route, Closest Facility and Service Area Analysis, this study belong to Service Area Analysis analysis's area, scilicet analysis supply water point's possible supply water area.

3. Material and Method

3.1 Match water pipe network

This study use King Ming part local area pipe line information and research material, at the same time because Hardy Cross method explore match water pipe network water pressure analysis, thus the study focus on local match water pipe lines, it doesn't explore household water supply pipe line. This study's area is listed in figure 1, valve A is water input point, and valve at pipeline end point doesn't have number.

Figure 1 Study's area

Secondary, before use Hardy Cross Method to analysis, you need to find pipe network loop, width, and flow direction materials for better discussion. This study is

going to pack up and simplify pipe network study area, mark loop, size, flow direction, use Hardy Cross method analysis estimate, simplify graphic shape and material as graph 2. From the graph we can understand, current pipe network has 6 loop, form by 18 pipe lines, the remaining pipe lines are pipe line end point or connection to other pipe network, they are not consider in loop analysis calculation, next, there are 13 valves controlling water supply in the loop.

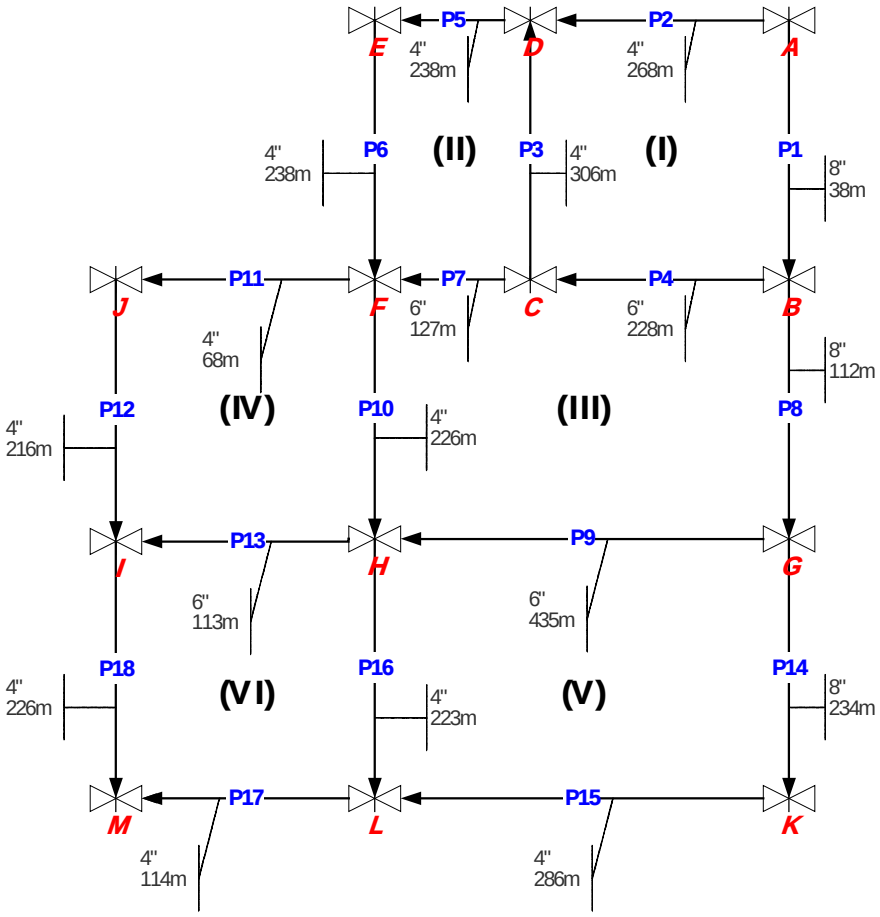

Figure 2 Simplify pipe network

The rest of valves at pipeline end point are not included in calculation also.

Table 1 Pipe properties

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
Size	8”	4”	4”	6”	4”	4”	6”	8”	6”	4”	4”	4”	6”	8”	4”	4”	4”	4”
Length	38m	268m	306m	228m	238m	238m	127m	112m	435m	226m	68m	216m	113m	234m	286m	223m	114m	226m

3.2 Pipe segment flow volume and value flow volume

This study plug above information into Hardy Cross method for analysis, to find every pipe segment’s flow volume, further using Hardy Cross Method’s basic assumption: user water collect point must be connection point (valve), and connection point inflow volume must equal to outflow volume. The analysis is focus on valve control, thus must calculate value’s flow volume, current study base pipe network map

analysis result, find each pipe segment valve, sum up to find each value's flow volume, detail analysis result is going to be discussed next segment.

3.3 User water use information

When perform pipe network analysis, beside each pipe segment, valve flow volume, must add each user's water user information to calculate the real flow volume, must use the result in network analysis. When calculating user water information, must estimate each pipe segment's actual user number, estimate each family has 4 people, each person use average water volume 200lpc, at the same time, according to assumption in pipe network water pressure analysis, water usage measurement is change to per second.

User's water usage volume is calculated as:

Ui=(Hix4x200)/86400

Ui: I pipe segment every segment user water user volume

Hi : I pipe segment number of user

After finding each pipe segment's user water usage, base on each pipe segment valve's inflow and outflow water volume, we can find each valve's actual flow volume.

4. Result and Discussion

Under different water supply volume, we will have different give water situation, for example, under a give water volume, it is possible for certain area's water supply to be not sufficient. Current study assume every second 6lps, 10lps water volume, analyze pipe network give water situation and compare it to traditional road map analysis method, the detail analysis result is describe below:

4.1 Traditional network analysis result

Traditional network analysis can only explore length or cost (water usage), can't add loop, flow direction and pipe width's factor, thus in current study each pipe segment will take exact same water supply volume from the same valve, at the same time, if

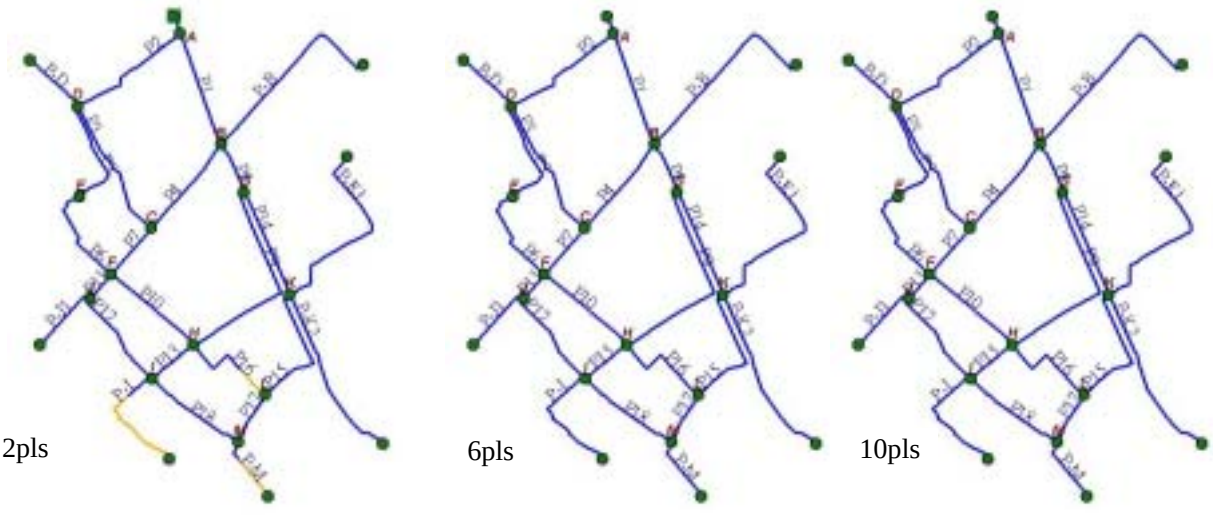

Figure 3 Traditional network analysis result

water supply is not sufficient, analysis result from pipeline end point begin to show insufficient water volume, at every second 2lps, 6lps, 10lps water supply volume, traditional network analysis result is listed below.

The above analysis result show, under every second 2lps condition, pipe segment P16, PI, PM water supply insufficient, but under every second 6lps and 10lps condition water supply is normal.

Because traditional network analysis method assume same water outtake condition is the same, from give water point begin to fulfill water usage demand, until give water volume equal to take water volume or network endpoint, thus traditional network analysis method doesn't consider special characteristic in pipe network like pipe width and loop.

4.2 Hardy Cross method analysis result

A. Pipe segment flow volume calculation

At first, plug last segment's pipe network information into formula and assume water head start from 100 ft, at every segment 2lps, 6lps, 10lps give water volume calculation result is listed below.

Table 2 Every kind of give water situation pipe segment flow volume chart.

Pipe ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
2lps	1.80	0.20	0.07	0.44	0.02	0.02	0.36	0.87	0.33	0.06	0.32	0.07	0.29	0.54	0.04	0.10	0.13	0.12
6lps	5.41	0.59	0.12	1.47	0.20	0.20	1.35	2.95	1.20	0.26	1.30	0.30	1.14	1.75	0.25	0.32	0.57	0.43
10lps	9.04	0.96	0.28	2.28	0.24	0.24	2.00	4.26	1.82	0.33	1.91	0.41	1.72	2.44	0.44	0.44	0.88	0.62

B. Valve net flow volume calculation

We can get each pipe segment inflow valve from pipe network map, according to inflow volume equal to outflow water volume's assumption, convert pipe segment flow volume calculation result to vale flow volume, calculation result is listed below.

Table 3 Every kind of give water situation vale flow volume, calculation result

Valve ID	A	B	C	D	E	F	G	H	I	J	K	L	M
2lps	2.00	1.80	0.44	0.27	0.02	0.38	0.87	0.39	0.37	0.32	0.54	0.13	0.25
6lps	6.00	5.41	1.47	0.70	0.20	1.55	2.95	1.46	1.43	1.30	1.75	0.57	1.00
10lps	10.0	9.04	2.28	1.24	0.24	2.24	4.26	2.15	2.12	1.91	2.44	0.88	1.50

C. Actual valve flow volume calculation

Actual give water situation must take user water usage into consideration, take last segment's user water usage volume into value flow volume calculation, scilicet value net flow volume subtract valve each second get water volume, can find each valve actual get water volume, then according to each valve supply pipe segment flow volume proportion to re-calculate lower pipe segment flow volume, repeat calculate to find each valve actual flow volume, at every second 2lps, 6lps, 10lps water get water volume calculation result listed below:

Table 4 Every kind of give water situation each valve actual flow volume

Valve ID	A	B	C	D	E	F	G	H	I	J	K	L	M
2lps	2.00	1.80	***-0.03***	***-0.47***	***-0.26***	***-0.07***	0.01	***-1.31***	***-0.74***	***-0.01***	0.54	***-0.88***	***-0.46***
6lps	6.00	5.41	1.00	***-0.04***	***-0.08***	1.10	2.09	***-0.25***	0.33	0.96	1.75	***-0.45***	0.29
10lps	10.0	9.04	1.82	0.50	***-0.04***	1.79	3.40	0.45	1.02	1.57	2.44	***-0.14***	0.79

Using above analysis result in network analysis, using valve point as facility point, use value actual volume as facility supply volume, doing network analysis, at same time each value has start point and end point's meaning. For example, a value is give water point's network can only serve P1 and P2, network end point is value B and D, at the same time valve B and D are also other pipe segment's give water point, etc.

Beside, above value can't give water represent upper pipeline can't give water sufficiently, after calculation analysis we find at give water volume 2lps only P15 pipe segment water take and give ration at 80%, the rest of pipeline insufficient ration is above 95%.

The result of using pipe network water pressure analysis method in network analysis has significant different to traditional network analysis.

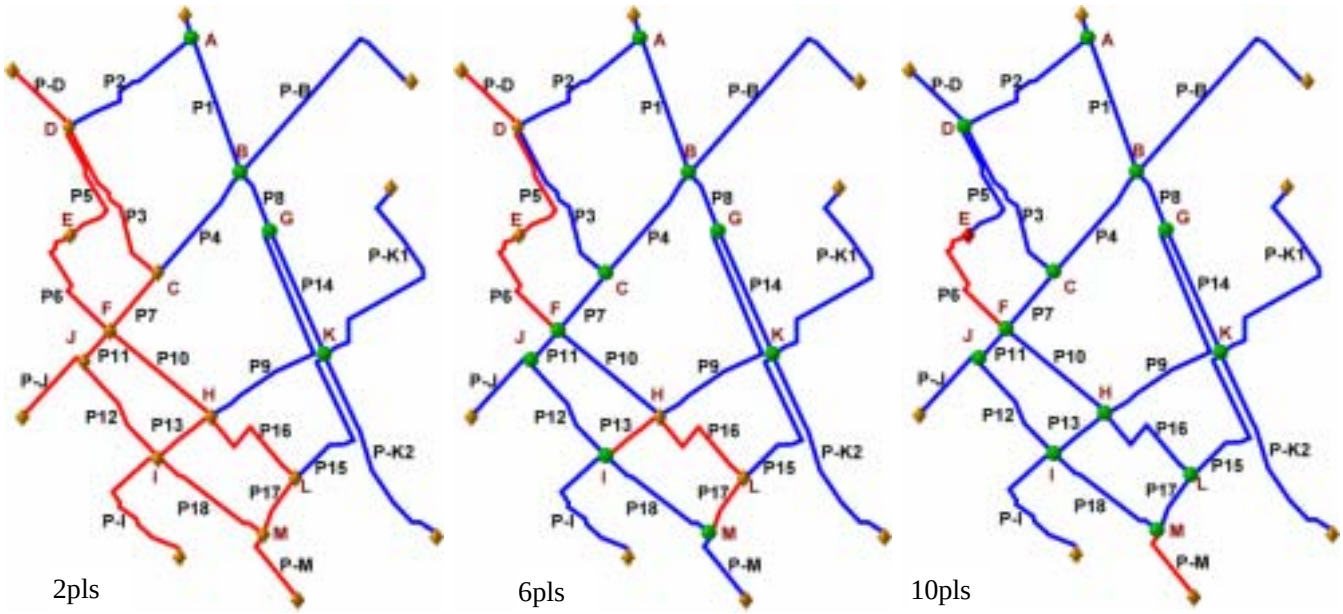

Figure 3 Every kind of give water situation analysis result

4.3 Decision support of water supply planning

From the study of the quantity of water supply alteration above, we can understand that hydraulic analysis and grid analysis technology can provide simulative platform which is closer to real circumstances for decision makers. At the same time, analysis of different quantity of water supply can also provide the proposal of pipeline configuration or renewal.

If current pipeline cannot quickly be renewed or modified, it is recommended to increase tank town for new source. Or simulate water supply plan by valve switch to change water supply network. The plan assumes only single water supply point and quantity is 2pls. please see below for related study:

A. Increase new source

Because pipeline P6 cannot normally supply water under different circumstances, we assume that new tank towns were built on valve D and J, and quantity of water supply is 2lps to study water supply circumstances. The result of flow recalculation is as following table:

Table 5 Real flow table of valves under various valves composites

Valve ID	A	B	C	D	E	F	G	H	I	J	K	L	M
from valve A	2.00	1.80	***-0.03***	***-0.47***	***-0.26***	***-0.07***	0.01	***-1.31***	***-0.74***	***-0.01***	0.54	***-0.88***	***-0.46***
from valve A and D	2.00	2.73	***-0.31***	0.68	0.29	0.97	0.92	***-0.70***	***-0.09***	0.77	1.10	***-0.53***	***-0.19***
	2.00	1.74	0.07	***-0.20***	***-0.02***	0.62	0.51	***-0.86***	0.02	1.14	0.93	***-0.60***	0.09

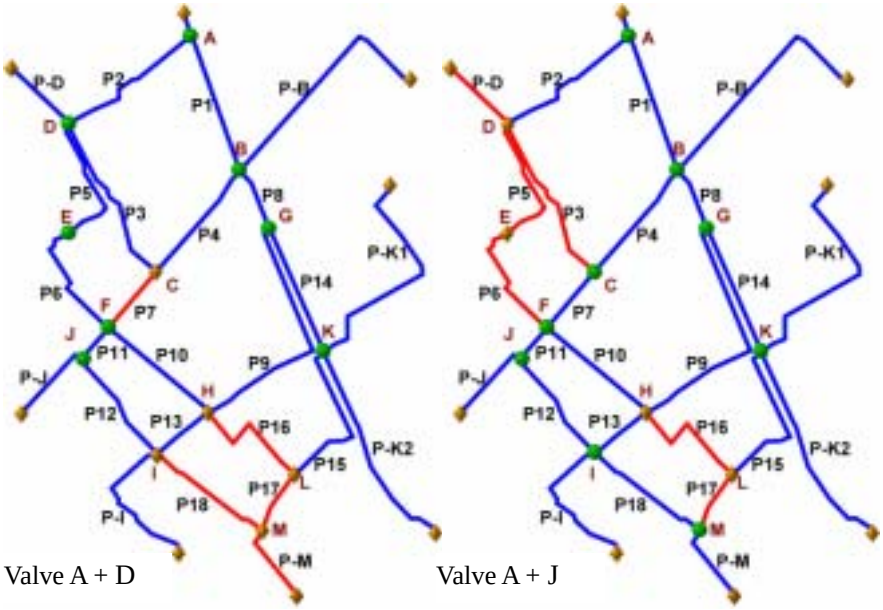

Figure 4 Result after increasing D and J valve water supply.

Comparing to original network configuration, increasing water supply point on valve D makes valve D、E、F、J、K supply water normally. Increasing water supply point on valve J, at the same time assume pipeline P11 had changed direction of water supply from valve J to valve F, valve C、F、J、K、M supply water normally comparing to original circumstances. We can acquire optimal position of water supply point through repeated tests.

B. Simulation of water supply plan

If the quantity of water supply cannot be increased, we need to study another water supply plan by shedding, and the water supply network should be redefined under such circumstances. This plan assumes that the water supply was ceased on P11, P12 (loop IV), P14, P15 (loop V), P17 and P18 (loop VI). Following table please find the alteration of water supply quantity.

Table 6 Real flow table of valves under various loop composites

Valve ID	A	B	C	D	E	F	G	H	I	J	K	L	M
ALL	2.00	1.80	***-0.03***	***-0.47***	***-0.26***	***-0.07***	0.01	***-1.31***	***-0.74***	***-0.01***	0.54	***-0.88***	***-0.46***
-IV	2.00	1.87	***-0.21***	***-0.60***	***-0.24***	***-0.17***	0.36	***-0.87***	***-0.41***	***-0.33***	0.67	***-0.71***	***-0.21***
-V	2.00	1.73	0.19	***-0.35***	***-0.27***	0.10	0.28	***-1.03***	***-0.54***	0.09	***-0.20***	***-0.78***	***-0.21***
-VI	2.00	1.80	0.22	***-0.49***	***-0.23***	0.01	0.02	***-1.33***	***-0.71***	0.11	0.49	***-0.99***	***-0.71***

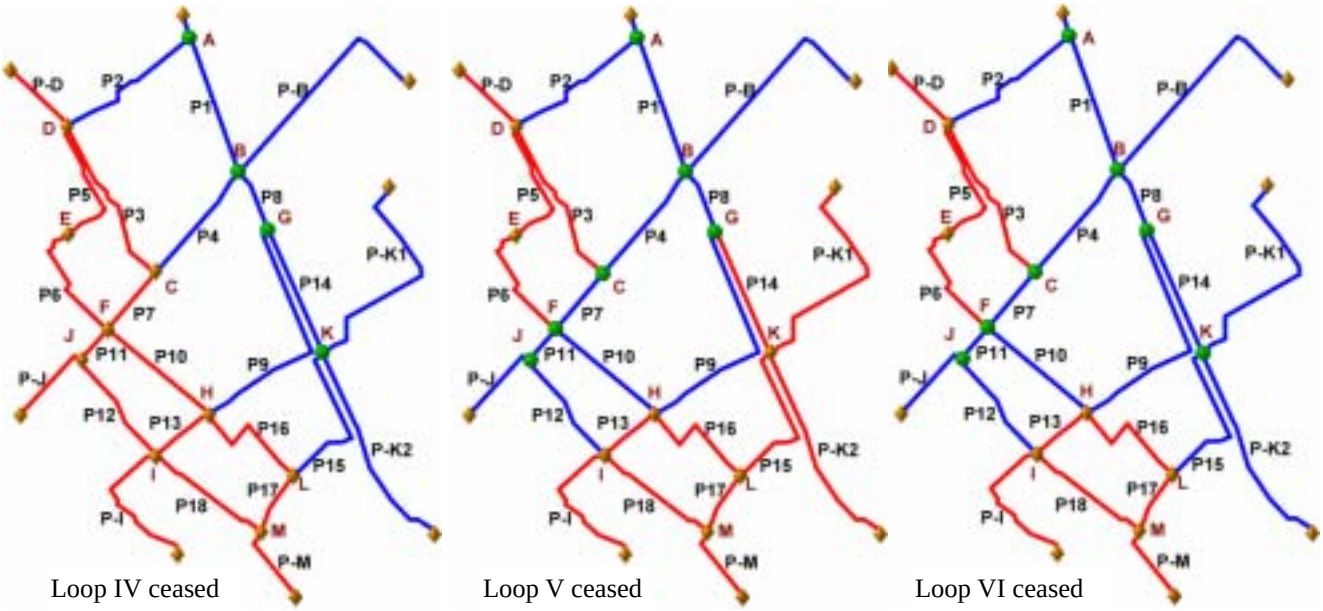

Figure 5 Result under various loop composites

From the result above we find that ceased supply of P11 and P12 (loop IV) cannot improve whole supply system. If the supply of P14 and P15 (loop V) are ceased, valve A,B,C,F,G,J can work normally. If the supply of P17 and P18 (loop VI) are ceased, valve A,B,C,F,G,J,K can work normally. We can acquire optimal water supply plan by composite analysis of supply plan.

5. Conclusion

Traditional network analysis consider all pipe segment as equal quality, distribute same water volume, when give water insufficient, analysis result's water insufficient area is depending on how far it is from give water station. In reality, pipe segment's pipe width has great influence to give water volume, large pipe width can make pipe segment further away from give water station to have sufficient water supply, from currently study area's PK2 pipe segment, small pipe width's pipe segment every though closer to give water station, like P3, P5 pipe segment, it is not possible to have normal give water, thus using pipe network water pressure analysis cant get more closer to reality's give water situation.

Secondly, value open or close will affect pipe network loop's distribution situation, directly affect pipe segment's water flow variation, thus after one valve on-off adjustment, need to redo calculation for all the loop, to find valve on-off adjustment, the

entire pipe network water volume supply changes, put analysis result into network to find valve open close adjustment's affecting area.

In read life give water environment, pipe segment's angle, material's characteristic will also affect give water situation, current study only focus exploring on length, pipe width's characteristic. In the future we can take all possible affecting pipe segment's characteristic into analysis, to find the most actual give water situation's pipe network analysis result, aside, combine user MIS information to analysis result can't find at give different give water situation, the affected household and population, then.

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