LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

MODELING OF NEW GRAVITY DIVERSIONS FOR CANAL 900 NETWORK

JULY 2013
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EXECUTIVE SUMMARY

The purpose of the LRBMS project is to set the ground for improved, more efficient and sustainable basin management at the Litani river basin through provision of technical support to the Litani River Authority and implementation of limited small scale infrastructure activities.

The project is composed of the following four components:

- 1: Building Capacity of the Litani River Authority (LRA) towards Integrated River Basin Management
- 2: Water Monitoring of the Upper Litani River
- 3: Integrated Irrigation Management
  - 3a: Participatory Agriculture Extension Program (PAEP)
  - 3b: Machghara Plain Irrigation Plan
- 4: Risk Management
  - 4a: Qaraoun Dam Monitoring System
  - 4b: Litani River Flood Management Model

As part of the component 3a, the irrigation system from Canal 900 was assessed. Canal 900 withdraws water from Qaraoun Lake for a large irrigation scheme of 2000 ha located in the southern parts of the Bekaa valley. Three pumping stations of different size deliver water to laterals through regulating upstream reservoirs. However, the off–farm irrigation system has been found unable to deliver simultaneously water to all farms with sound adequacy. Nowadays, only 1/3 of the planned irrigated area is being supplemented with water from Canal 900 although Structural & operational improvements were implemented on canal 900 networks with the support of Litani River Basin Management Support (LRBMS) Program with the aim to increase the extent of the irrigated area and improve the supply/demand flow balance within the project area.

Direct deliveries from Canal 900 will alleviate the limited capacities of the three pump stations and allow an increase in the area served by the Canal 900 system. They will also lower operational costs by significantly reducing the energy needed to pump water from the canal to the reservoirs.

The evaluation of the hydraulic performance of Canal 900 pressurized irrigation network at the light of the newly constructed gravity diversions along the Canal in Joub Jannine and Lala was made using a simulation model, EPANET 2 (United States Environmental Protection Agency).

EPANET was chosen to perform these simulations since it is widely used world-wide and notably in the US where it is the model for the majority of networks models. EPANET is freely available on Internet, and is maintained and regularly updated by the Environmental Protection Agency. Due to its friendlyuser platform, the model offers a series of scenarios and options that can be adopted under different water/pressure conditions.

Simulations of the Canal 900 irrigation system

Afirst set of simulations were made in order to evaluate the actual behavior and the maximum capacity of the actual systems consisting of the three sub-networks constituting Canal 900 irrigation system (i.e. K1, K2 and JJ-KL) and their related branches which were added separately. Two simulations were made:

- The first one based on the effective farms' demand experienced over the last growing year (2012) as being noted down by Litani River Authority (LRA),
- and the second based on a maximum velocity of 2 m/s in all the pipes constituting the network.

The main goal of this work was to simulate the hydraulic behavior of Canal 900 and analyze the hydraulic operational features (i.e. pressure/flow/friction) along them. The results are as follows:

- The actual irrigated area ranges between 640 ha and 800 ha which is equivalent to about 85% of the pumps capacity.
- The maximum irrigated area if additional pumps are to be added ranges between 1520 ha and 1900 ha.

Simulations of the Diversions

The specific objective of this work was to simulate the two gravity diversions in Lala (LL) and JoubJannine (JJ), with relation to the flow/pressure of water flowing into them and delineate the irrigated areas served by the two gravity diversion systems. An ultimate objective was to evaluate whether Canal 900 off-farm irrigation system was capable to deliver water to the designed farms adequately and efficiently.

Gravity water supplies at specific points along Canal 900 irrigation conveyor were revealed in previous studies conducted by Litani River Basin Management Support (LRBMS) Program as corrective measures to balance between the increasing farmers' demand and limited supply of the initially designed hydraulic system. This considers branching into the current irrigation pipelines of the gravity diversion pipelines conveying water directly from the Canal into Lala and Joub-Jannineirrigation sub-networks. Then, the deliberated gravity served sub-networkswere hydraulically split into one (LL) and two (JJ) irrigation zones that are supplied with water from the gravity diversion facilities, whereas the rest of the areas receives water from the already existing upstream reservoirs.

For that, we assumed first two simulation scenarios: (1)simulation based on 50% of the totaldemand of the initial design flow and (2)simulation based on 75% of the total demand of the initial design flow. For each scenario, three options were taken; (O1) area served by the gravity diversion that is located in the lower part of the designed irrigation area; (O2) area served by the gravity diversion that is located in the upper part of the designed irrigation area and (O3) area served by the gravity diversion is distributed adequately between the different sectors. For the three above-mentioned options, nodes with less than 30 m of head pressure and pipes with more than 2 m/s of water velocity were identified.As a result of these simulations, it was deducted that:

- The adequate distribution between the different sectors in each diversion can lead to a larger total flow (O3).
- The capacity of each diversion is related to the pressure constraints which are also related to the irrigation type to be adopted.

Based on the results of the above mentioned simulations, it was decided to test the capacities of the diversions for the suitable flow if drip irrigation is to be adopted. Two pressure constraints for each diversion were tested at 15 m and 20 m of pressure head.

The results are as follows:

- For a minimum pressure of 15m, the projected irrigated area from the two diversions ranges between 285 ha and 355 ha which is equivalent to an addition of about 45% to the Canal 900 network capacity.
- For a minimum pressure of 20m, the projected irrigated area from the two diversions ranges between 230 ha and 285 ha which is equivalent to an addition of about 35% to the Canal 900 network capacity.

Conclusion

The simulation on EPANET showed that the introduction of the diversions can increase the irrigated area from Canal 900 from a range between 640ha and 800ha to a range between 1150ha and 1440ha.

It should be noted that in practice, several other factors related to losses inside the networks, lack in the management system, non permanent peak demands, electrical power cut-off... can affect the above mentioned figures.

The model built can be used by the LRA in order to simulate the behavior of the system at the beginning of the irrigation season in order to assess the water availability and the pressures on nodes based on the real time demand.

ملخص تنفيذي

يهدف مشروع "دعم إدارة حوض نهر الليطاني" هو التحضير لإدارة حوض نهر الليطاني بفعالية وإستدامة أكبر من خلال الدعم الفني للمصلحة الوطنية لنهر الليطاني و تنفيذ نشاطات محدودة الحجم معها:
ويتألف المشروع من العناصر الأربعة التالية:

١. : بناء القدرات ضمن المصلحة الوطنية لنهر الليطاني لإدارة متكاملة لحوض النهر
٢. : مراقبة نوعية المياه في الحوض الأعلى لنهر الليطاني
٣. : إدارة متكاملة للري:
٣- أ : برنامج توسيع الزراعة التشاركية
٣- ب : مخطط ري سهل مشفرة
٤. : إدارة المخاطر:
٤- أ : نظام مراقبة سد القرعون
٤- ب : نموذج إدارة فيضانات نهر الليطاني

وكجزء من العنصر ٣ أ فقد تم مسح نظام الري في القناة ٩٠٠. تسحب القناة ٩٠٠ مياهها من بحيرة القرعون لشبكة ري كبرى مساحتها ٢٠٠٠ هكتار في المناطق الجنوبية لوادي البقاع. وتقوم ثلاث محطات ضخ بطاقات مختلفة لتوزيع المياه على جوانب القناة ٩٠٠ بتنظيم دفق المياه الى الخزانات التي تغذيها. لكن نظام الري لم يتمكن من إيصال المياه بالوقت ذاته لكامل الحيازات الزراعية بالكميات المناسبة. وبالوقت الحاضر يروي فقط ثلث المساحة المفروض ريها من القناة ٩٠٠ بالرغم من الحسينات الإنشائية و التشغيلية التي جرى تنفيذها على شبكة القناة ٩٠٠ بمساعدة "برنامج دعم إدارة حوض نهر الليطاني" بهدف زيادة المساحة المروي وتحسين التغذية بالمياه و الطلب عليها ضمن نطاق المشروع.

ان التحويل المباشر للمياه من القناة ٩٠٠ يخفف الضغط على القدرات المحدودة لمحطات الضخ الثلاث ويسمح بتوسيع المساحات المروية من القناة ٩٠٠. كما أنه سيخفض أكلاف التشغيل بتخفيض بشكل ملموس الطاقة اللازمة لضخ المياه من القناة الى الخزانات.

وقد جرى تقييم الأداء المائي لشبكة الري المضغوطة بعد تنفيذ التحويلات الجديدة بالجاذبية من القناة في جب جنين ولالا بواسطة نموذج للمحاكاة "إيبانات ٢" المعتمد في وكالة حماية البيئة الأميريكية تم إختيار "إيبانات" لإجراء المحاكاة باعتبارها معتمدة عالميا وخاصة في الولايات المتحدة حيث يستعمل هذا النموذج في معظم نماذج الشبكات. و"إيبانات" متوفر دون بدل عن الإنترنيت وتقوم وكالة حماية البيئة الأميريكية بصيانته و تحديثه بانتظام. وبفضل كونه سهل الإستعمال فان هذا النموذج يقدم ساساة من السيناريوهات و الخيارات التي يمكن تبنيها أخذا بالإعتبار الشروط المائية و ضغط الشبكات.

نماذج المحاكاة التي طبقت على نظام القناة ٩٠٠

بعد إجراء عدد من نماذج المحاكاة بهدف تقييم الممارسات الحالية ومعرفة القدرات القصوى للشبكات الحالية المؤلفة من ثلاث شبكات قانونية تؤلف نظام القناة ٩٠٠ للري(أي ك١ وك٢ وك ل و جج) وتفرعاتها التي أضيفت مستقلة عن الشبكة الأساسية و قد تمت عمليتا محاكاة:

. الأولى مبنية على الطلب الفعلي لمياه من قبل المزارع التي تم إحصاؤه خلال السنة السابقة(٢٠١٢) من قبل المصلحة الوطنبة لنهر الليطاني

. أما الثانية المبنية على السرعة القصوى للمياه البالغة ٢م/ث في كافة خطوط القساطل التي تتشكل الشبكة منها

الهدف الأساسي من هذا العمل هو محاكاة السلوك المائي للقناة ٩٠٠ وتحليل عوامل التشغيل المائي(ضغظ/تصريف/احتكاك) على طول الخطوط المذكورة. وكانت النتائج كما يلي:

. تتراوح المساحة المروية حاليا ما بين ٦٤٠ و٨٠٠ هكتار أي ما يوازي ٨٥% من طاقة المضخات

. ان المساحة القصوى التي يمكن ريها فيما إذا أقيمت مضخات إضافية تتراوح ما بين ١٥٢٠ و١٩٠٠ هكتار

عمليات محاكاة التحويلات

كان الهدف الأساسي لهذا العمل محاكاة التحويليين للمياه بالجاذبية في لالا (لل) وجب جنين (جج) و علاقتها بالتصريف المائي/الضغط ضمن خطي التحويل و تحديد المساحات المروية من كل من التحويليين بالجاذبية. أما الهدف النهائي الآخر فكان تقدير ما إذا كانت القناة ٩٠٠ من نظام الري هذا قادرة على تصريف الكميات بشكل مناسب وفعال للمساحات المخطط ريها. وقد تبين أن التغذية بالجاذبية في نقاط معينة من القناة ٩٠٠ قد سبق لبرنامج دعم إدارة حوض نهر الليطاني ان قامت بدرسها كتدبير تصحيحي للموازنة بين حاجات المزارعين المتزايدة و كمية الياه المحدودة التي جرى التصميم المائي على أساسها. ويعتمد المشروع تحويل المياه بالجاذبية مباشرة من القناة الى قساطل الري الحالية العائدة للشبكتين الثانويتين بمنطقتي لالا وجب جنين من خلال التحويليين بالجاذبية بينما باقي المناطق تتلقى مياهها من الخزانات العليا المنشأة سابقا.
لذلك افترضنا ان تعمل على سيناريوهين من المحاكاة:

١-محاكاة مبنية على ٥٠% من الطلب الإجمالي على المياه حسب الدراسة المائية الأساسية.
٢-محاكاة مبنية على ٧٥% من مجموع الطلب على المياه حسب الدراسة المائية الأولية.

وقد اعتمدت ثلاثة خيارات في كل من السيناريوهيين: (٠١) المنطقة المغذاة بالتحويل في الجزء الأسفل من المساحة المروية حسب الدراسة و(٠٢) المنطقة المغذاة بالتحويل بالجاذبية في الجزء الأعلى من المساحة المروية حشب الدراسة و(٠٣) المنطقة المغذاة بالتحويل بالجاذبية بشكل توزع فيه المياه حسب الحاجة في مختلف الأجزاء. وقد جرى الحرص في الخيارات الثلاثة ان لا يزيد اضغط عن ٢٠ مترا في العقد وان لا تزيد سرعة المياه عن ٢م/ث في القساطل. و بنتيجة عمليات المحاكاة هذه تم استنتاج ما يلي:

. ان التوزيع حسب الحاجة بين مختلف الأجزاء في مختلف المساحات من كل تحويل يؤدي الى تصريف مائي أكبر(٠٣)

. امكانية كل تحويل تتوقف على الضغط في القساطل الذي يتبع طريقة الري المعتمدة

واعتمادا على النتائج التي اعطتها عمليات المحاكاة المذكورة تقرير اختبار طاقة التحويلات هذه للتصريف المناسب فيما إذا اعتمد الري بالتنقيط. وقد تمت تجربة ضغطين كلل تحويلة الأولى على ١٥م والثانية عشرين مترا وكانت النتائج كما يلي:

. بضغط أدنى قدره ١٥م بلغت المساحة المروية من التحويلين ما بين ٢٨٥ و ٣٥٥ هكتار ما يوازي إضافة ٤٥% على طاقة شبكة القناة ٩٠٠

. وبضغط ادنى قدره ٢٠م بلغت المساحة المروية من المتحويليين ما بين ٢٣٠ و٢٨٥ هكتار ما يوازي اضافة ٣٥% على طاقة شبكة القناة ٩٠٠

الخلاصة

أظهرت المحاكاة على "إيبانيت" ان استعمال التحيليين يمكن زيادة المساحة المروية منم القناة ٩٠٠ من ٦٤٠-٨٠٠ هكتار الى ما يتراوح بين ١١٥٠-١٤٤٠ هكتار. ويجدر الذكر انه بالواقع هناك عوامل عدة تتعلق بالخسارة ضمن لشبكات و ضعف نظام الإدارة والذروات غير المستمرة في الطلب على المياه وانقطاع التيار الكهربائي...هذه العوامل كافة يمكنها التأثير على الأرقام المذكورة أعلاه.

ويمكن للمصلحة الوطنية لنهر الليطاني الإستفادة من النموذج المذكور اعلاه لمحاكاة كيفية عمل النظام في بداية فصل الري لمعرفت توفر المياه و الضغوطات عند العقد حسب الطلب الحقيقي في وقته.

General

Canal 900 withdraws water from Qaraoun Lake for a large irrigation scheme of 2000 ha located in the southern parts of the Bekaa valley. Three pumping stations of different size deliver water to laterals through regulating upstream reservoirs. However, the off–farm irrigation system has been found unable to deliver simultaneously water to all farms with sound adequacy. Nowadays, only 1/3 of the planned irrigated area is being supplemented with water from Canal 900 although Structural & operational improvements were implemented on canal 900 networks with the support of Litani River Basin Management Support (LRBMS) Program with the aim to increase the extent of the irrigated area and improve the supply/demand flow balance within the project area.

Therefore, the evaluation of the hydraulic performance of the current system and introduced gravity diversions should be performed taking into consideration the effective demand of farms experienced over the last period. Particular emphasis should be placed on the conveyance capacity of main gravity pipeline running from the main reservoir to network branches.

The EPANET software, a computer program that performs simulations of the hydraulic behavior within a pressurized pipe network, was used to perform the above reproduction. The main functions of this software are:

- Tracks the flow of water in each pipe
- Tracks the pressure at each node
- Calculate the height of water in upstream tanks/reservoirs
- Computes friction head loss (using Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas)
- Simulate water quality within the network

EPANET is designed to improve the understanding of skilled staff on the system performance analysis. It runs under Windows and provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats, including network maps, data tables, time series graphs, and contour plots.

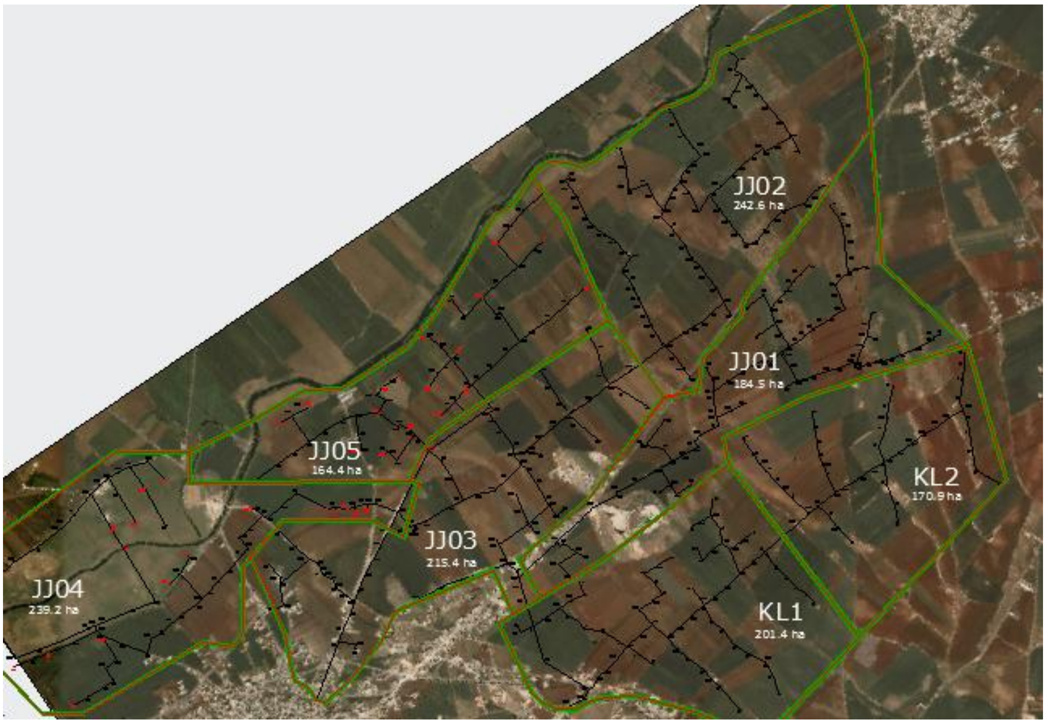
1. Scope of Work

The present work is undertaken within the frame of Component 3 (Integrated Irrigation Management) of LRBMS Program with the aim to:

- Analyze the hydraulic operational features (pressure/flow/friction) of Canal 900 system:
  - Simulate the hydraulic behavior of Canal 900 irrigation system with the actual water demand (2012 subscriptions) and based on a velocity constraint of 2m/s. All branches constituting the system, i.e. K1, K2 & JJ/KL, included separately.
  - Add the gravity diversions in K2 and JJ as separate branches.
  - Simulation and delimitation of the additional land that can be irrigated from the diversions.
- Evaluate whether the system has been capable to deliver water to the designed farms with adequacy

2. Simulations of Canal 900 irrigation system

The delimitation and subdivisions of Joub Jannine and K2 irrigation networks are shown in figure the figure below:



The hydraulic Behavior of Canal 900 irrigation system was simulated twice. All branches constituting the system, i.e. K1, K2 & JJ/KL, included separately:

- With the actual water demand (2012 subscriptions).
- And based on a velocity constraint of 2m/s.

The results of these simulations are illustrated in Appendix A for the actual water demand and in Appendix B for the 2 m/s velocity constraint.

The following table illustrates the results in addition to the corresponding irrigation area in reference to the irrigation water demand (1 l/s/ha and 1.25 l/s/ha):

Zones	Actual Demand		Capacity (2 m/s)	
	1.25 l/s/ha	1.00 l/s/ha	1.25 l/s/ha	1.00 l/s/ha
JJ1	42	53	192	240
JJ2	42	52	162	203
JJ3	82	103	58	73
JJ4	23	29	103	129
JJ5	67	84	95	119
KL1	61	76	234	292
KL2	55	69	163	204
Total JJ KL	**373**	**466**	**1008**	**1260**
K21	24	30	36	45
K22	11	14	57	71
K23	43	54	33	41
K24	107	134	183	229
Total K2	**186**	**232**	**309**	**386**
Total K1	**79.2**	**99**	**200**	**250**
Total	**638**	**797**	**1517**	**1896**

In addition to the two simulations, the irrigated area for several total flows in reference to the pumps capacity is illustrated in the table below:

Zones	Total Area	100% of pumps capacity		85% of pumps capacity		75% of pumps capacity	
		1.25 l/s/ha	1.00 l/s/ha	1.25 l/s/ha	1.00 l/s/ha	1.25 l/s/ha	1.00 l/s/ha
JJ1	148	58	73	49	62	44	55
JJ2	217	85	107	73	91	64	80
JJ3	172	68	85	58	72	51	63
JJ4	191	75	94	64	80	56	70
JJ5	194	76	95	65	81	57	72
KL1	161	63	79	54	67	48	59
KL2	137	54	67	46	57	40	51
Total JJ KL	**1220**	**480**	**600**	**408**	**510**	**360**	**450**
K21	58	22	28	19	24	17	21
K22	59	23	28	19	24	17	21
K23	79	30	38	26	32	23	28
K24	239	92	114	78	97	69	86
Total K2	**435**	**167**	**208**	**142**	**177**	**125**	**156**
Total K1	**267**	**83**	**104**	**71**	**89**	**63**	**78**
Total	**1922**	**730**	**913**	**621**	**776**	**548**	**684**

3. Simulations of the Diversions

In order to simulate the behavior of the diversions under different operation conditions, several demand distributions and values were simulated:

- Diversion K2
  - 3 distribution options for a total demand equal to 50% of the design flow.
  - 3 distribution options for a total demand equal to 75% of the design flow.
- Diversion JJ
  - 3 distribution options a total demand equal to 25% of the design flow.
  - 3 distribution options for a total demand equal to 50% of the design flow.

The results of these simulations are illustrated in Appendix C for the diversion K2 and in Appendix D for diversion JJ.

The following can be deducted from the above mentioned simulations:

- The adequate distribution between the different sectors in each diversion can lead to a larger total flow (Refer to option 3 of each simulation).
- The capacity of each diversion is related to the pressure constraints which is also related to the irrigation type to be adopted.

Based on the results of the above mentioned simulations, it was decided to test the capacities of the diversions for the suitable flow if drip irrigation is to be adopted. Two pressure constraints for each diversion were tested 15 and 20 m. The details of these simulations are illustrated in Appendix E for the diversion K2 and in Appendix F for diversion JJ.

The following table illustrates the results in addition to the corresponding irrigation area in reference to the irrigation water demand (1 l/s/ha and 1.25 l/s/ha):

Zones	Irrigated Area for a Minimum Pressure 15 m		Irrigated Area for a Minimum Pressure 20 m	
	1.25 l/s/ha	**1.00 l/s/ha**	**1.25 l/s/ha**	**1.00 l/s/ha**
JJ4	107	133	93	117
JJ5	118	147	97	121
K22	59	74	38	48
Total	**284**	**355**	**228**	**286**

APPENDIX A Simulation of Canal 900 irrigation system based on the actual water demand (2012 Subscriptions)

A.1: JJ-Joub Jannine and Kamed El Lawz Network

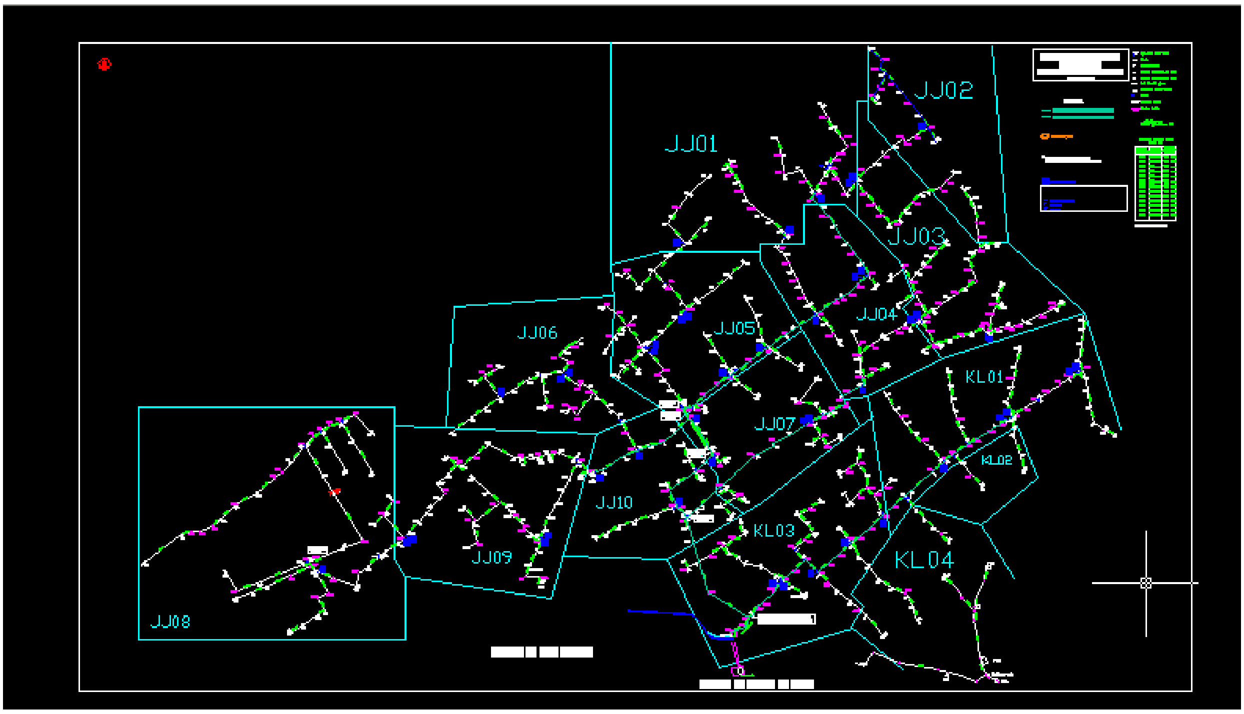


Figure A-1 JJ – KL Irrigation Networks

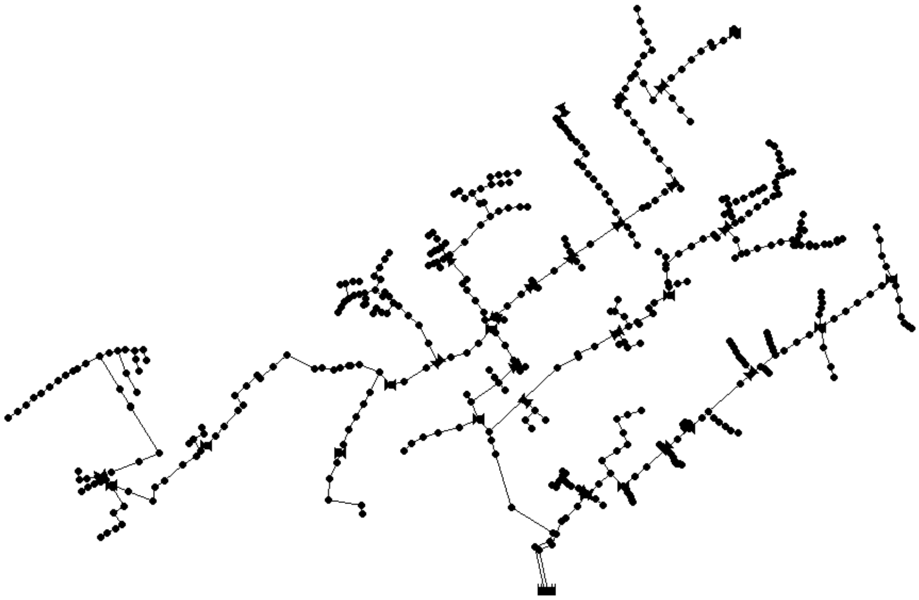


Figure A-2 JJ – KL EpaNet Model

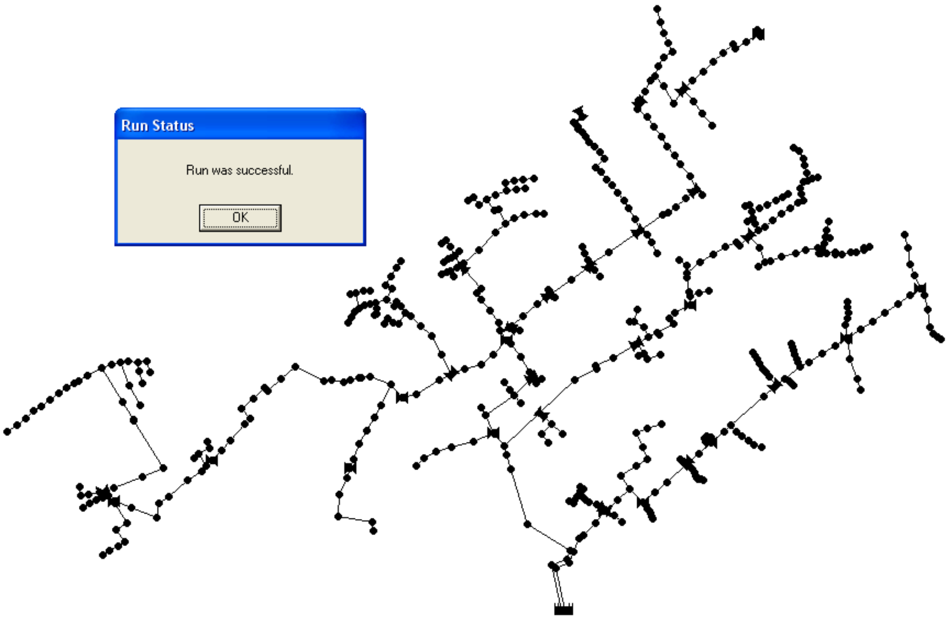


Figure A-3 JJ – KL Successful Run

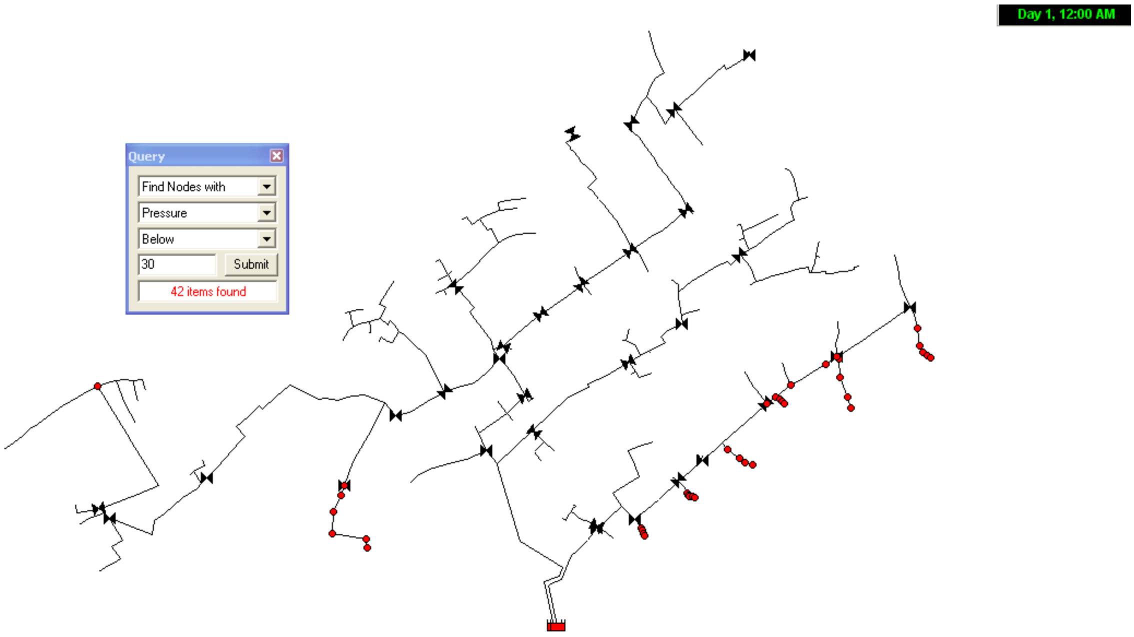


Figure A-4 JJ – KL Nodes with Pressure below 30m

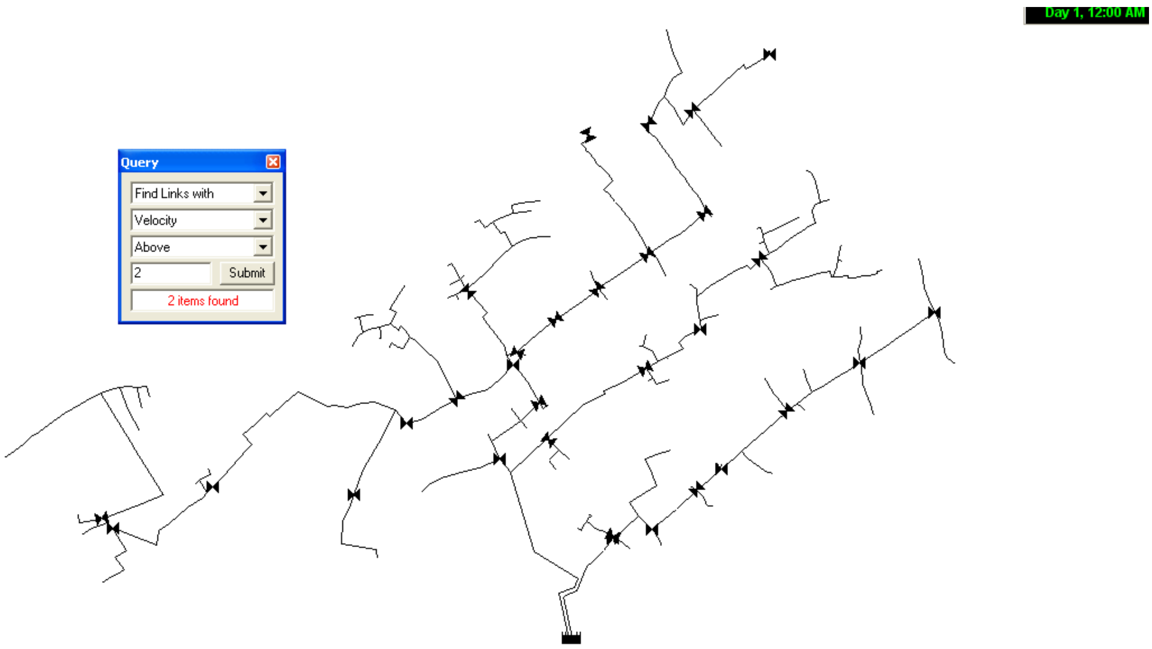


Figure A-5 JJ – KL Pipes with Velocity above 2m/s

A.2: K1 Network

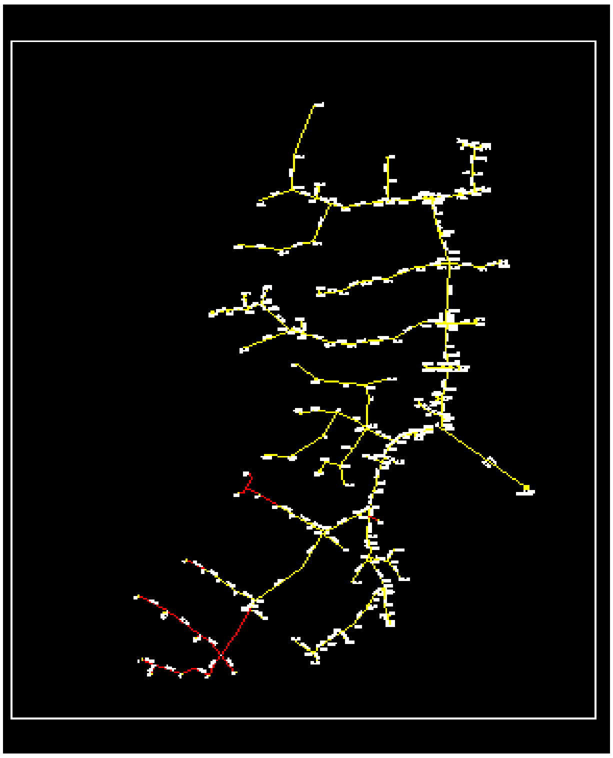


Figure A-6 K1 Irrigation Networks

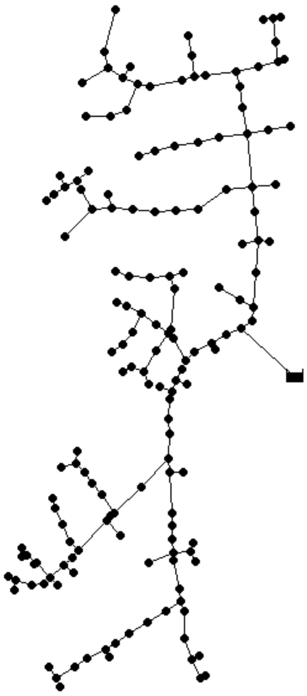


Figure A-7 K1 EpaNet Model

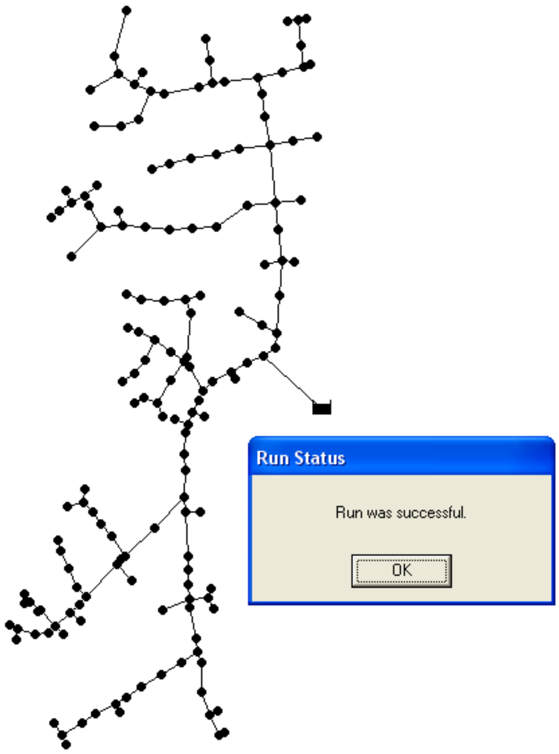


Figure A-8 K1 Successful Run

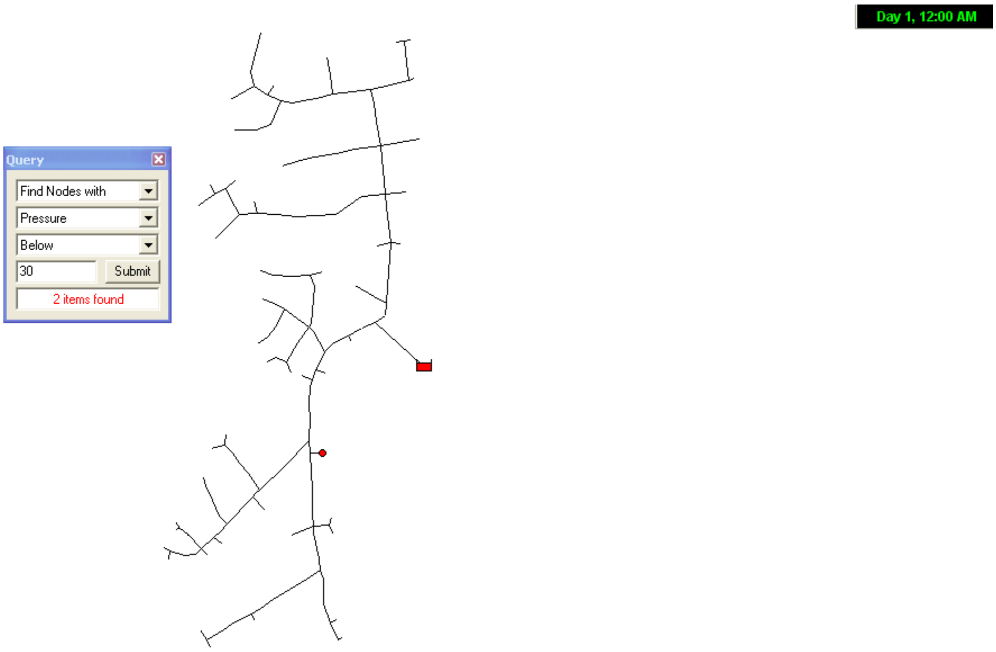


Figure A-9 K1 Nodes with Pressure below 30m

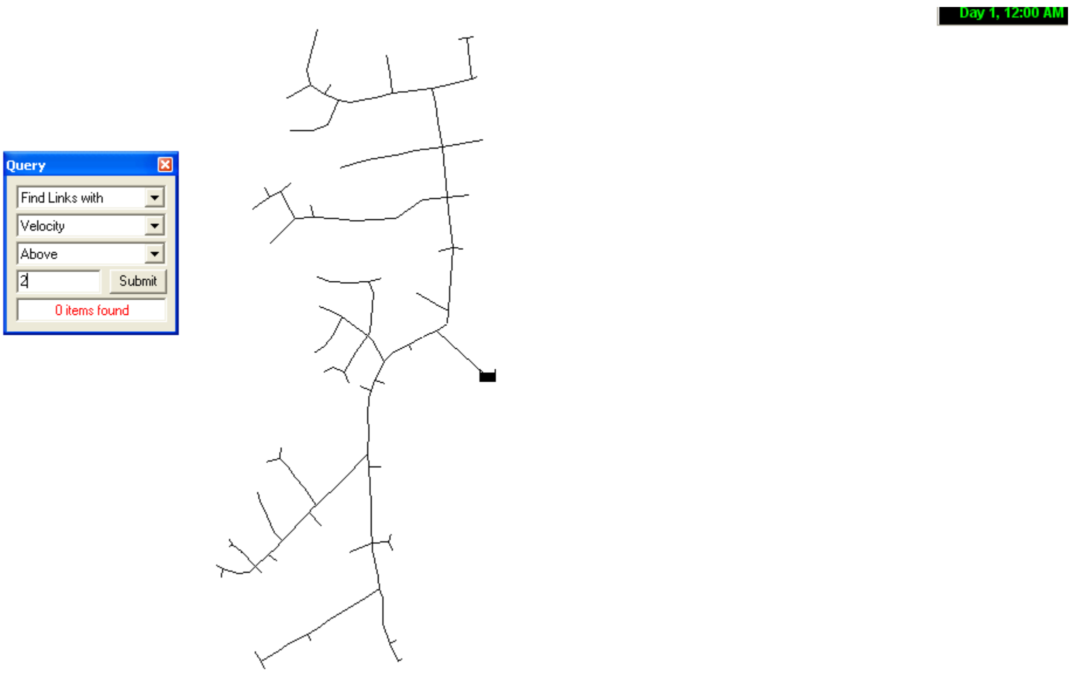


Figure A-10 K1 Pipes with Velocity above 2m/s

A.3: K2 Network

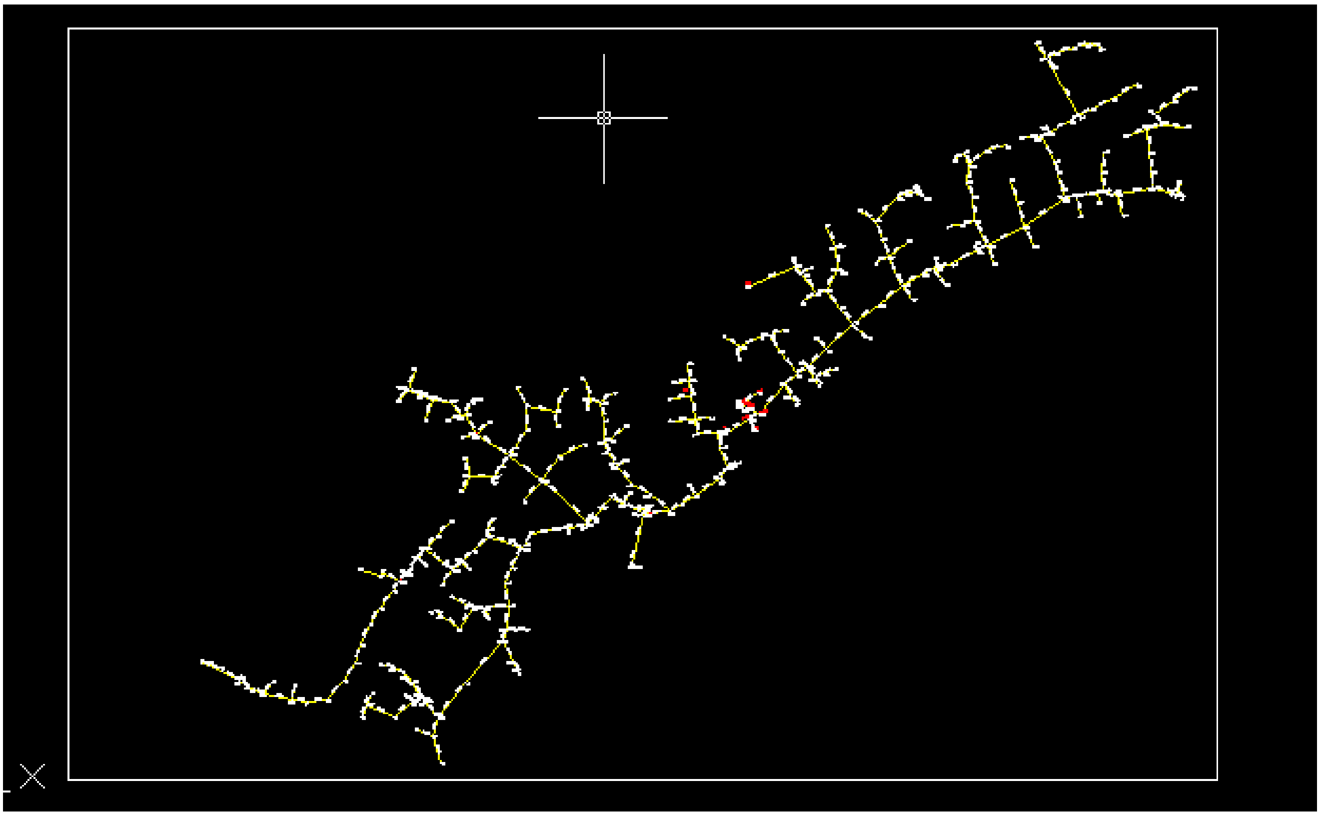


Figure A-11 K2 Irrigation Networks

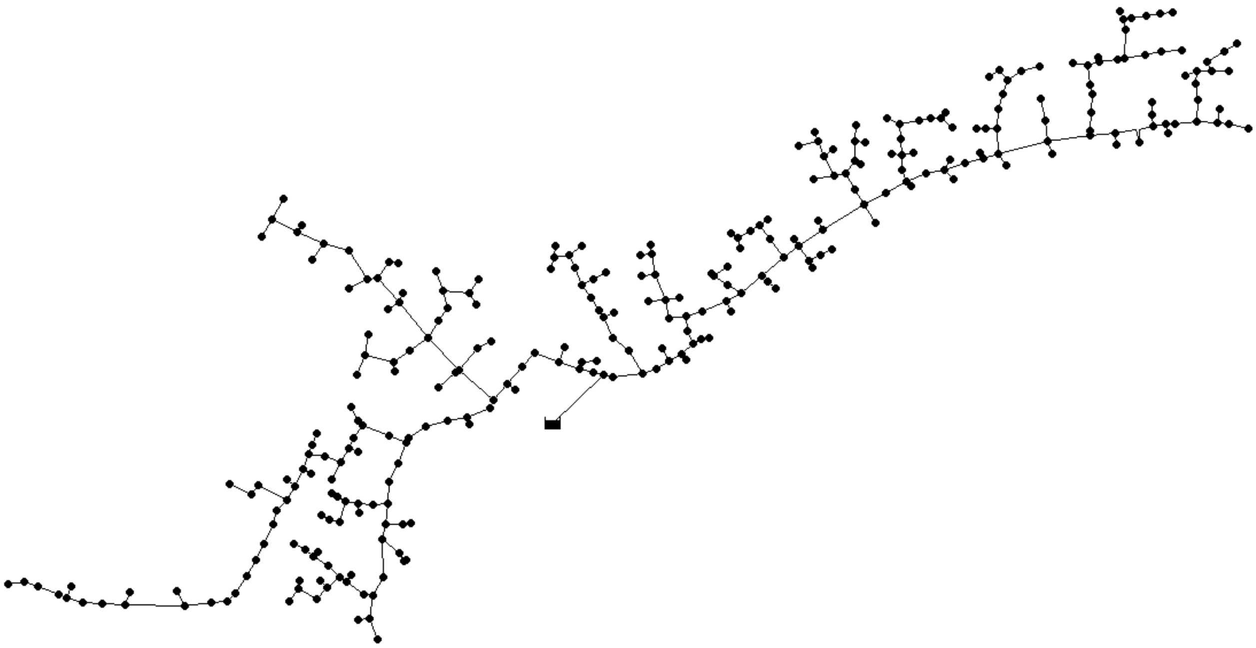


Figure A-12 K2 EpaNet Model

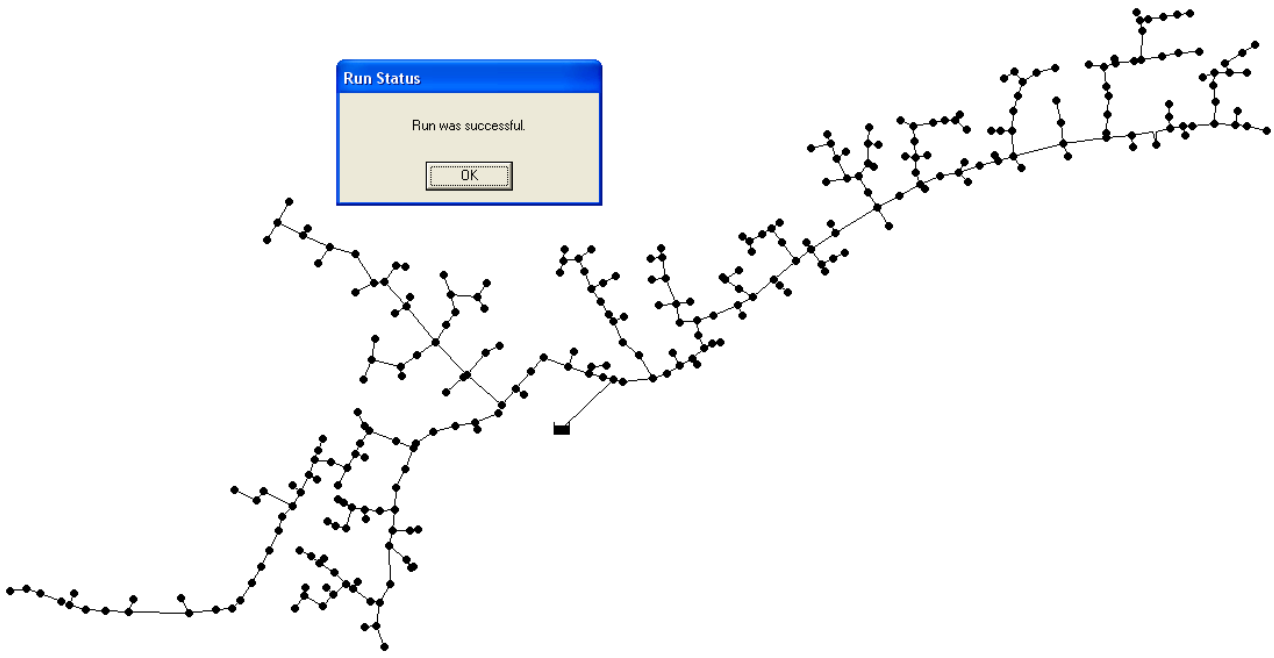


Figure A-13 K2 Successful Run

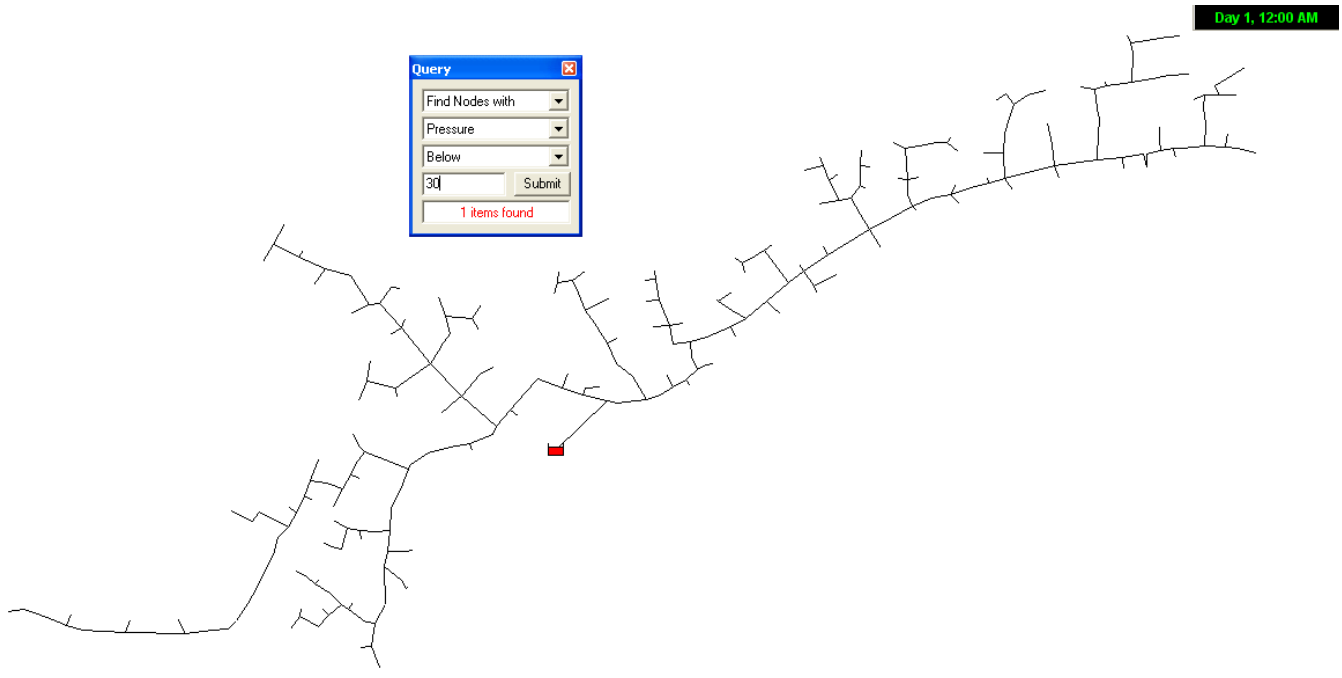


Figure A-14 K2 Nodes with Pressure below 30m

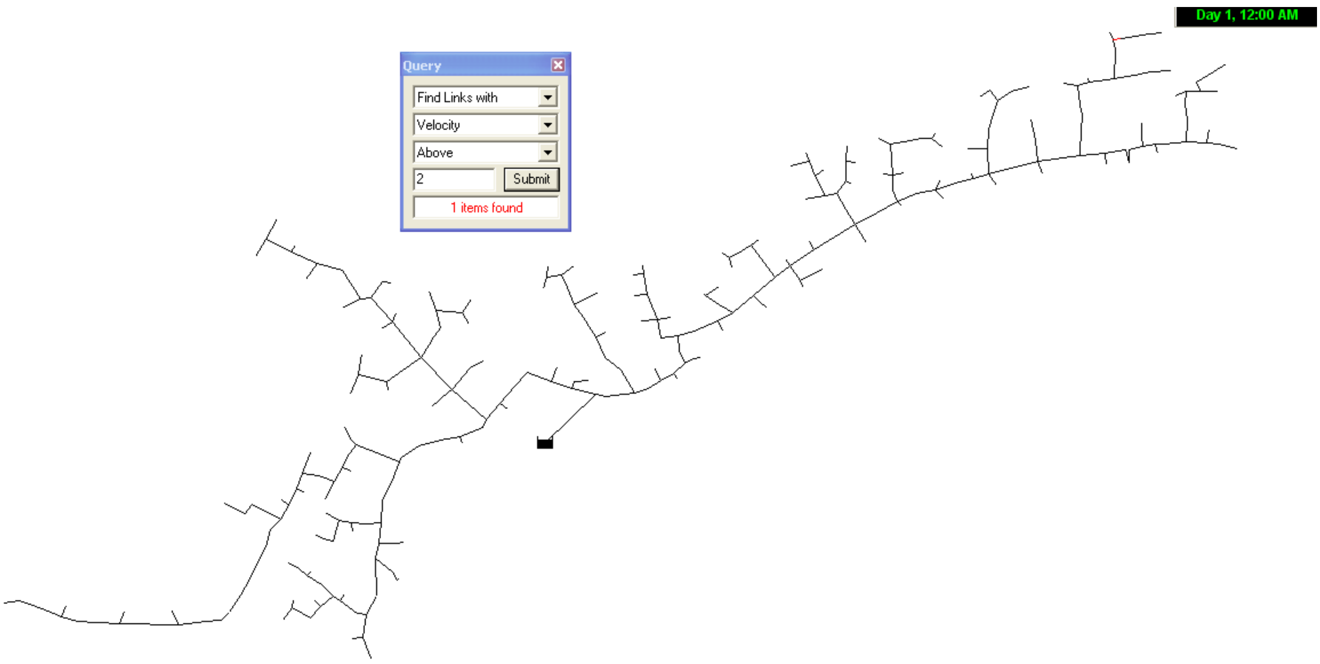


Figure A-15 K2 Pipes with Velocity above 2m/s

APPENDIX B Simulation of Canal 900 irrigation system based on 2 m/s velocity constraint

B.1: Joub Jannine and Kamed El Lawz Network

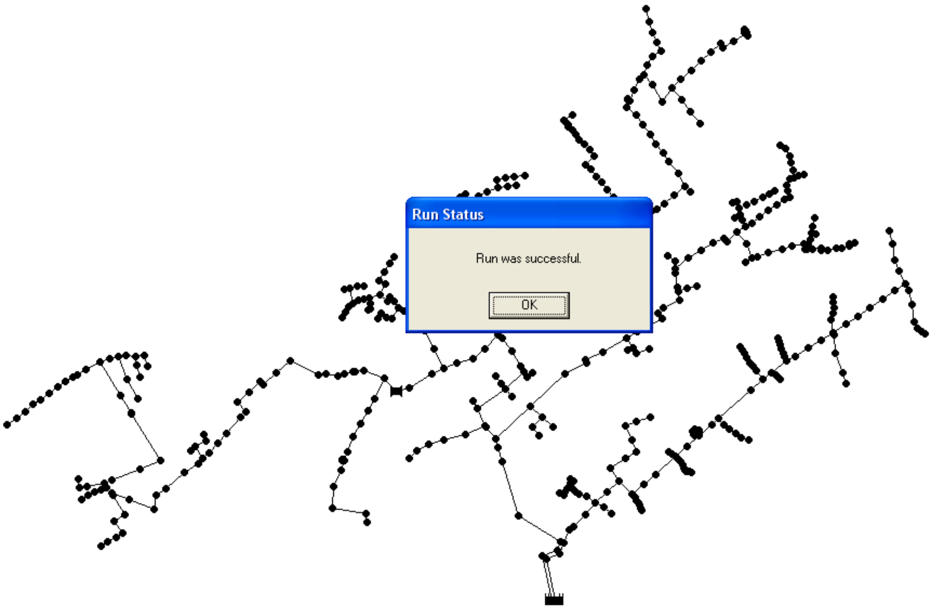


Figure B-1 JJ – KL Successful Rum

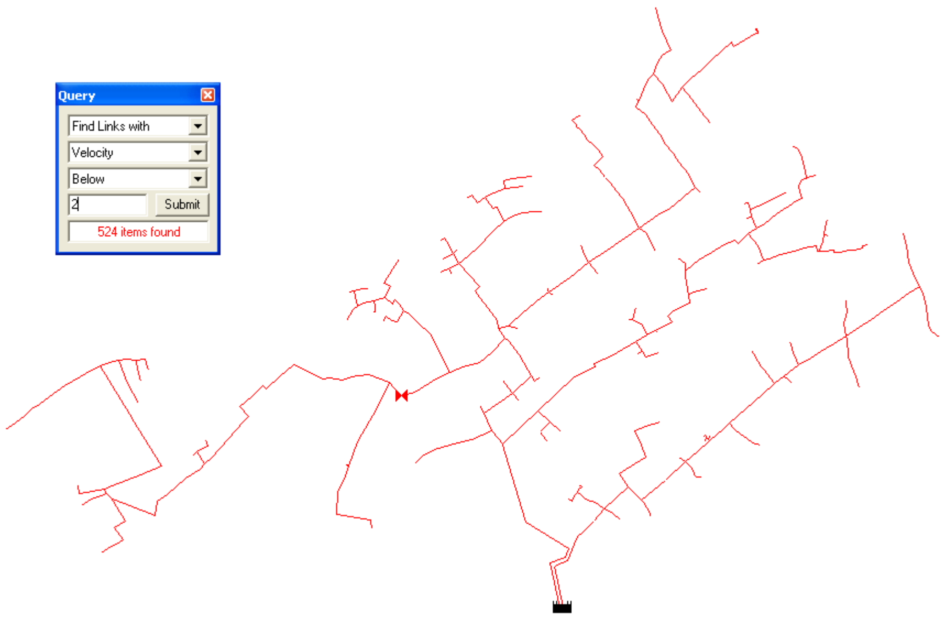


Figure B-2 JJ – KL Pipes with velocity below 2m/s

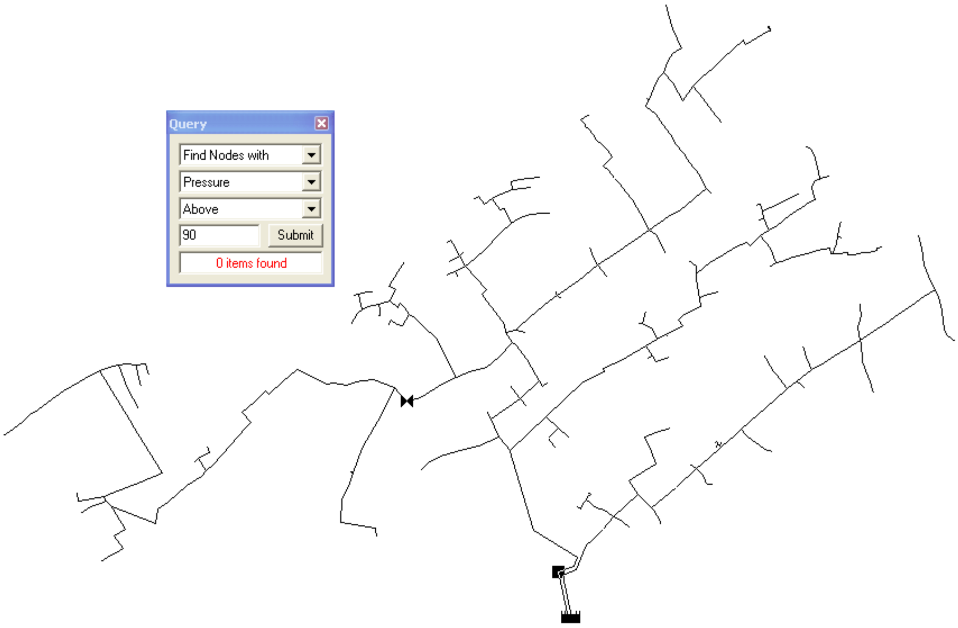


Figure B-3 JJ – kL

B.2: K1: Network

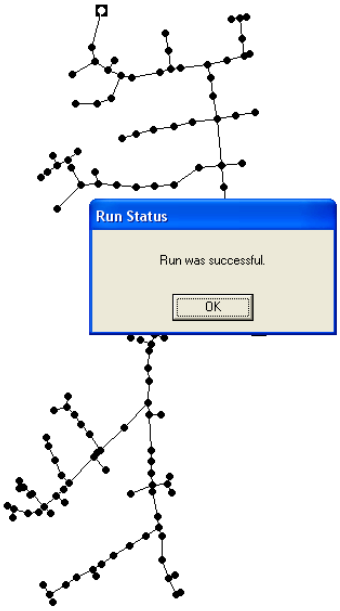


Figure B-4 K1 Successful Rum

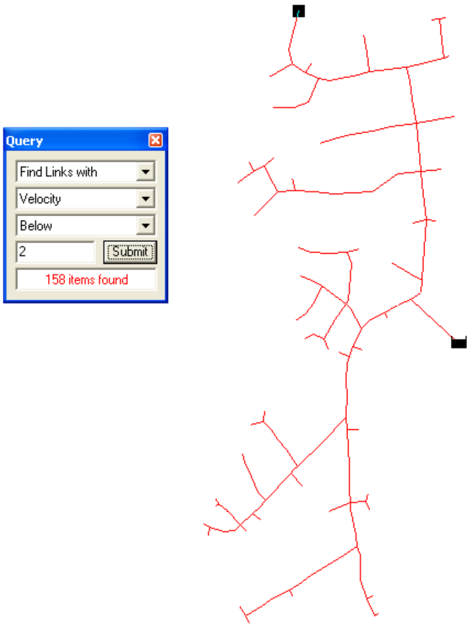


Figure B-5 K1 Pipes with velocity below 2m/s

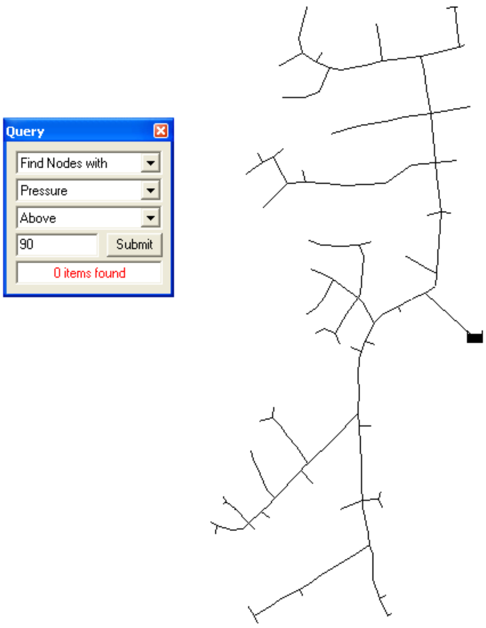


Figure B-6 K1 Nodes with pressure above 90m

B3: K2 Network

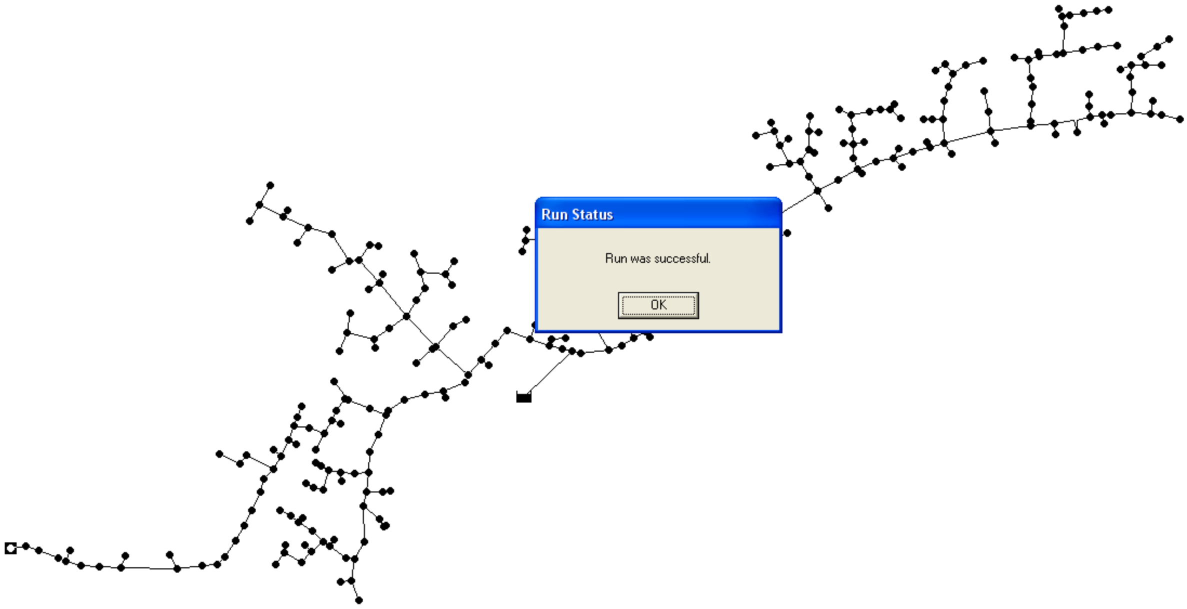


Figure B-7 K2 Successful Rum

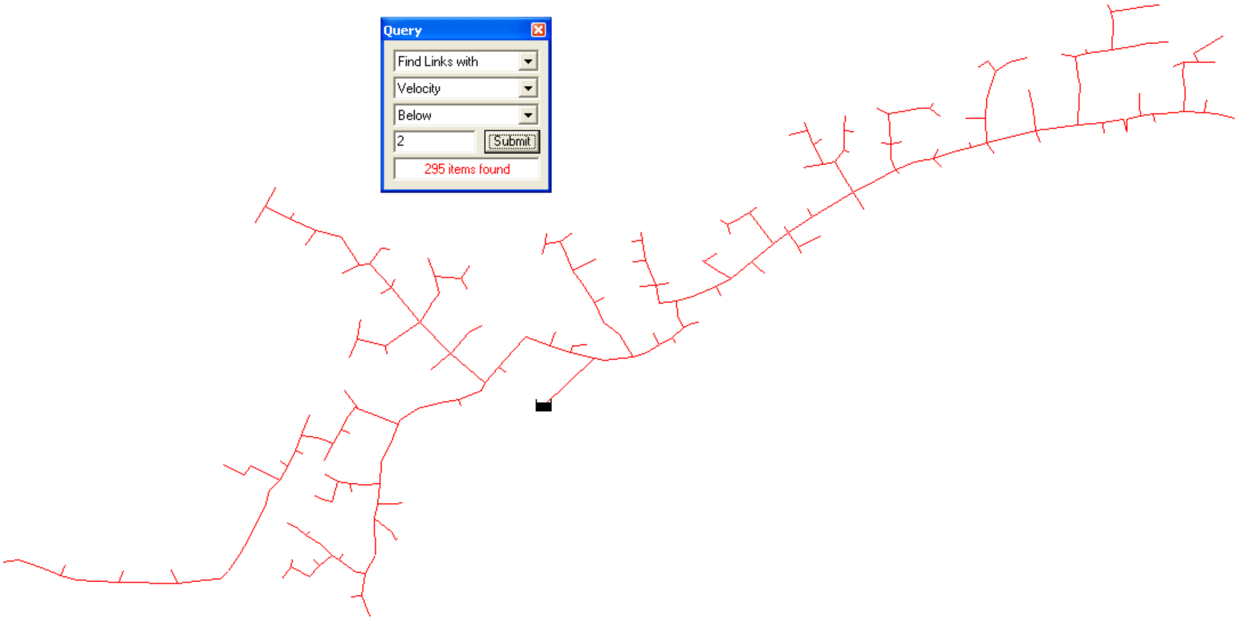


Figure B-8 L2 Pipes with velocity below 2m/s

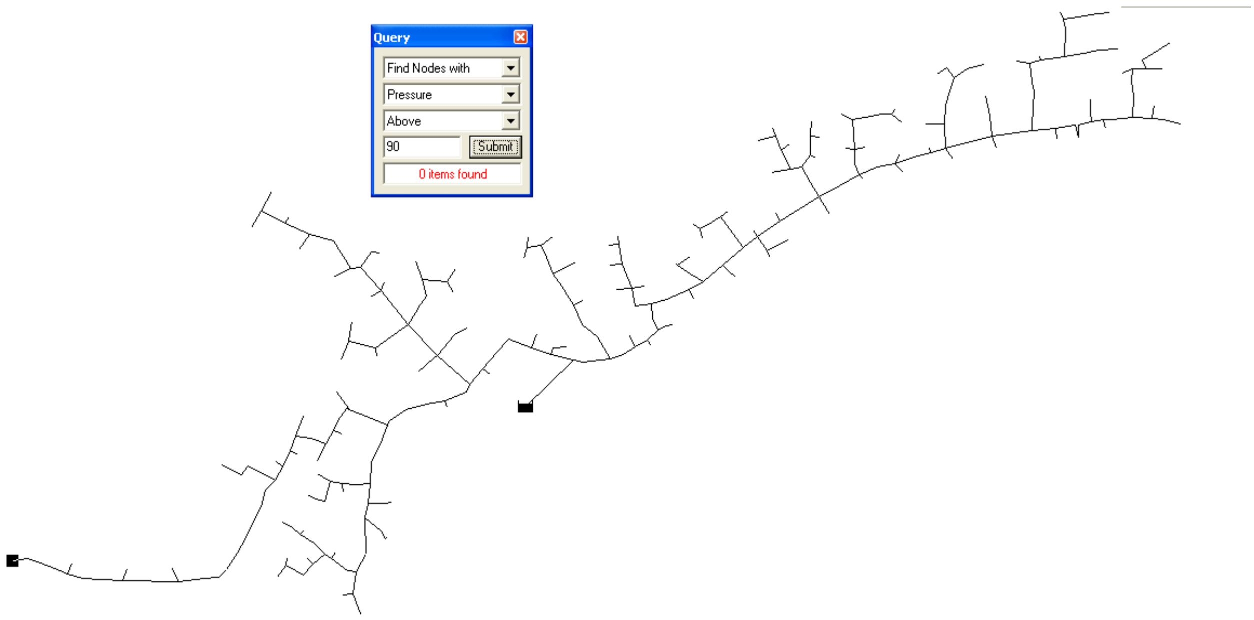


Figure B-9 K2 Nodes with pressure above 90m

APPENDIX C Simulation of K2 Diversion based on percentage of design flow

Figure C-1 Diversion K2

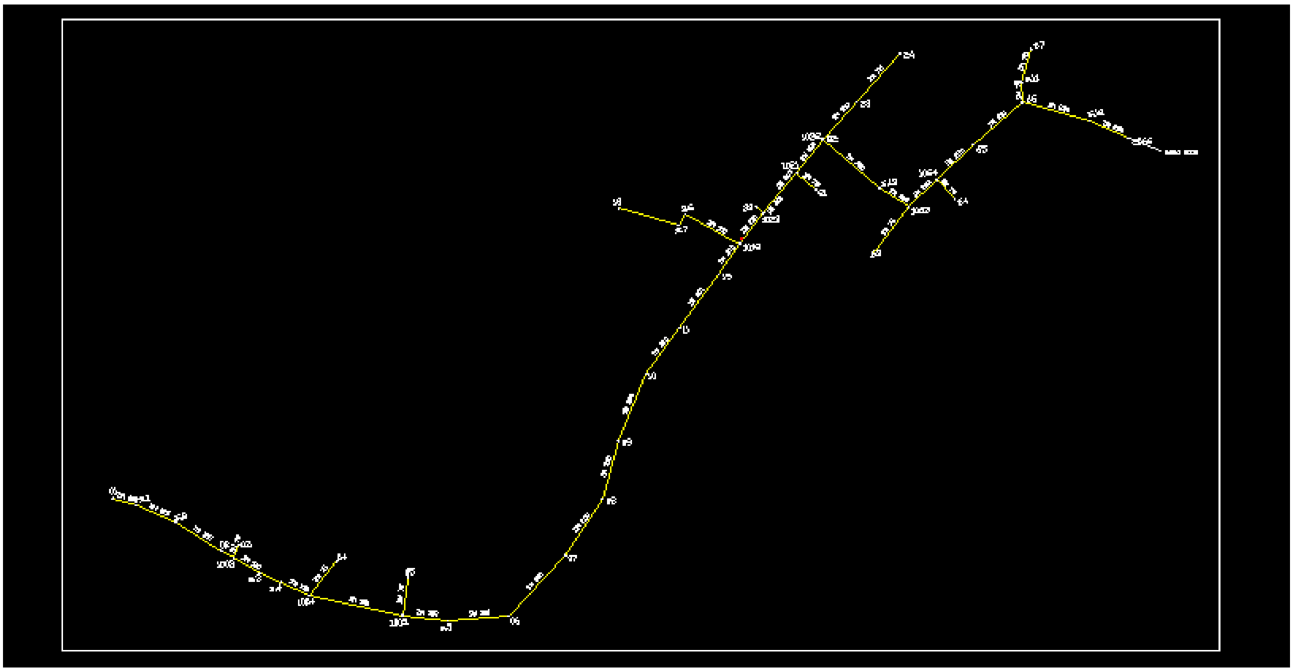


Figure C-2 Diversion K2 Irrigation Networks

Table 1 Diversion K2 Flow Repartition

K2-Diversion							
Node	**Demand**	**75%**			**50%**		
		O1	**O2**	**O3**	**O1**	**O2**	**O3**
1	2	2		2	2		2
2	2	2			2		
3	3	3		3	3		
4	3	3		3	3		3
5	2	2		2	2		2
6	2	2	2		2		
7	2	2	2	2	2		2
8	2	2	2		2		
9	2	2	2	2	2		2
10	2	2	2		2		
11	2	2	2	2	2		
18	4	4	4	4		4	4
19	2	2	2		2		
20	2		2	2		2	
21	2	2	2	2		2	2
22	2	2	2	2		2	
23	2	2	2	2		2	
24	2	2	2	2		2	2
63	2		2	2		2	2
64	2		2	2		2	2
65	2		2			2	
66	2		2			2	
67	2		2	2		2	2
Total	**50**	**38**	**38**	**36**	**26**	**24**	**25**
Percentage		**76**	**76**	**72**	**52**	**48**	**50**

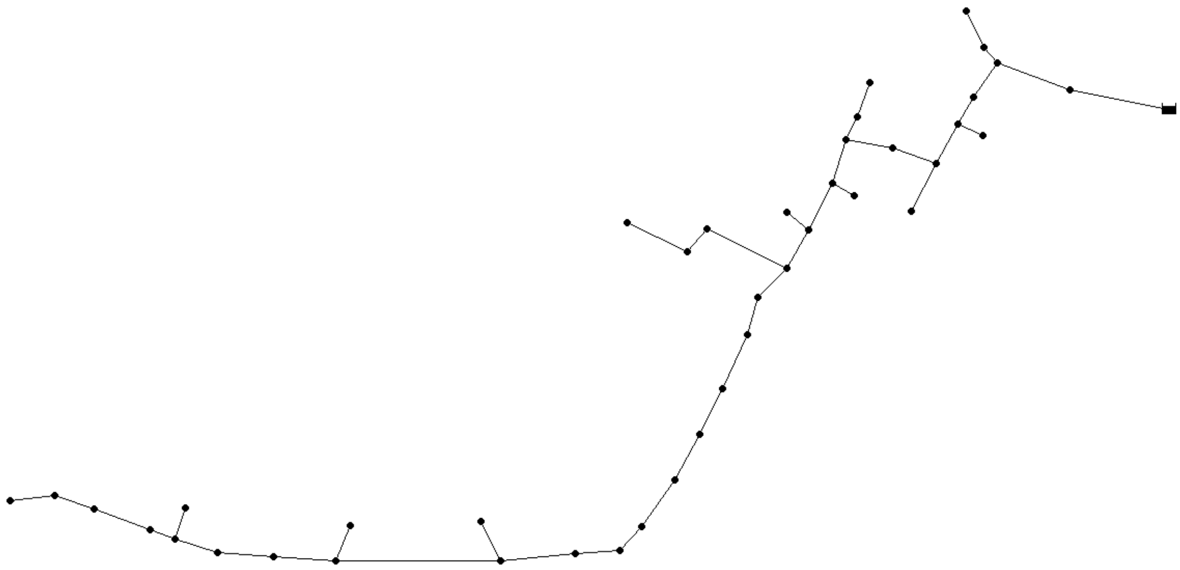


Figure C-3 Diversion K2 EpaNet Model

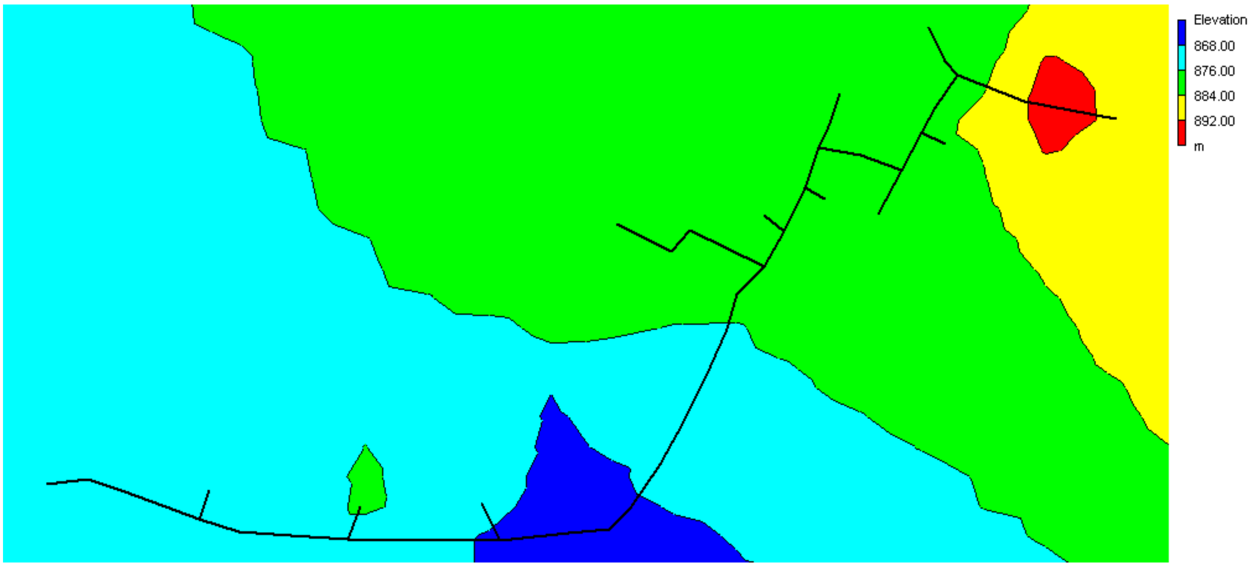


Figure C-4 Diversion K2 – Static Pressure Graph

C1: K2-50%-Options 1, 2 & 3

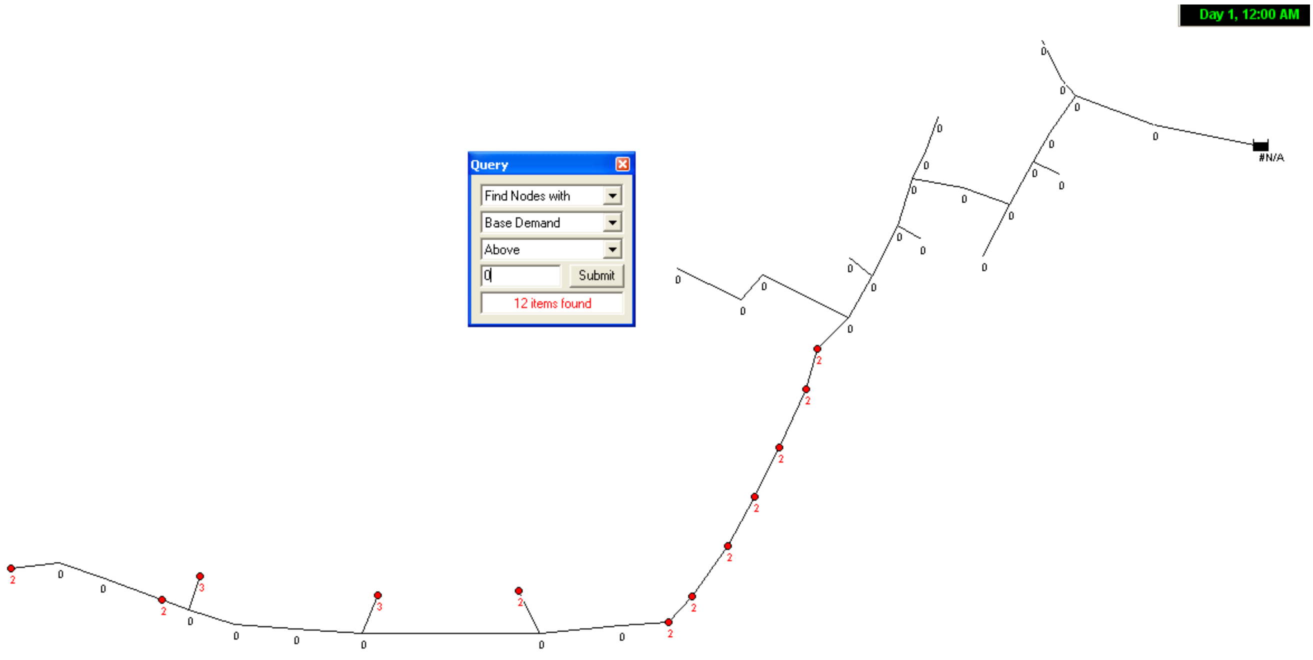


Figure C-5 Diversion K2 Demand Based on 50% Flow – Option 1

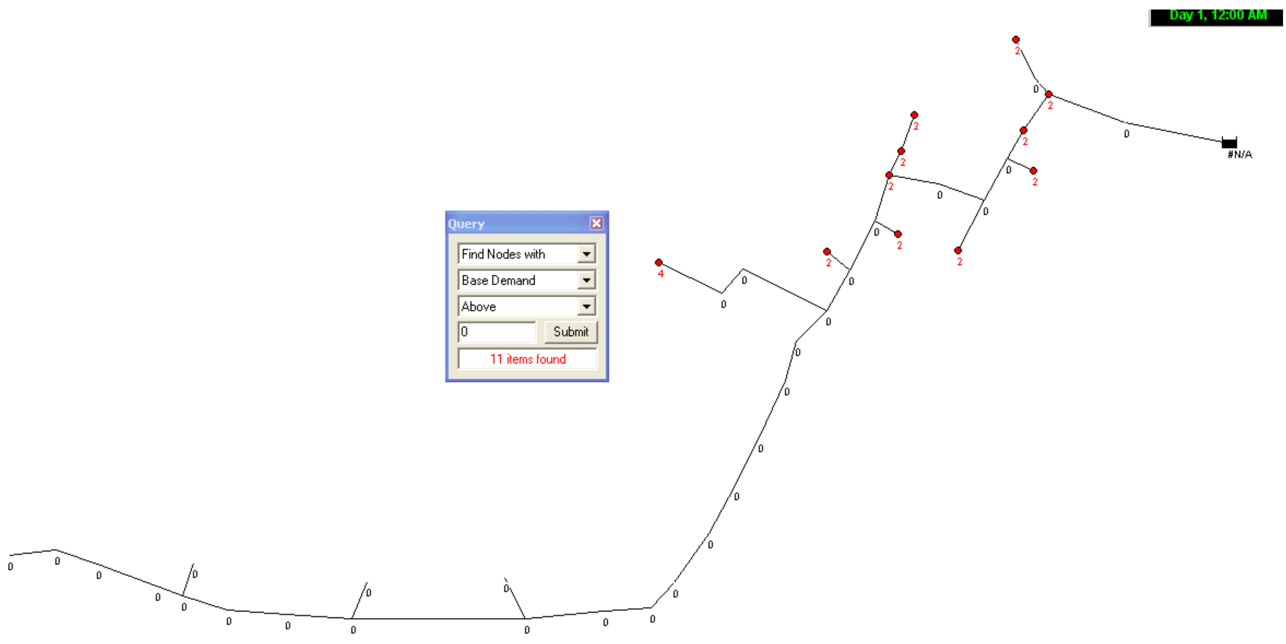


Figure C-6 Diversion K2 Demand Based on 50% Flow – Option 2

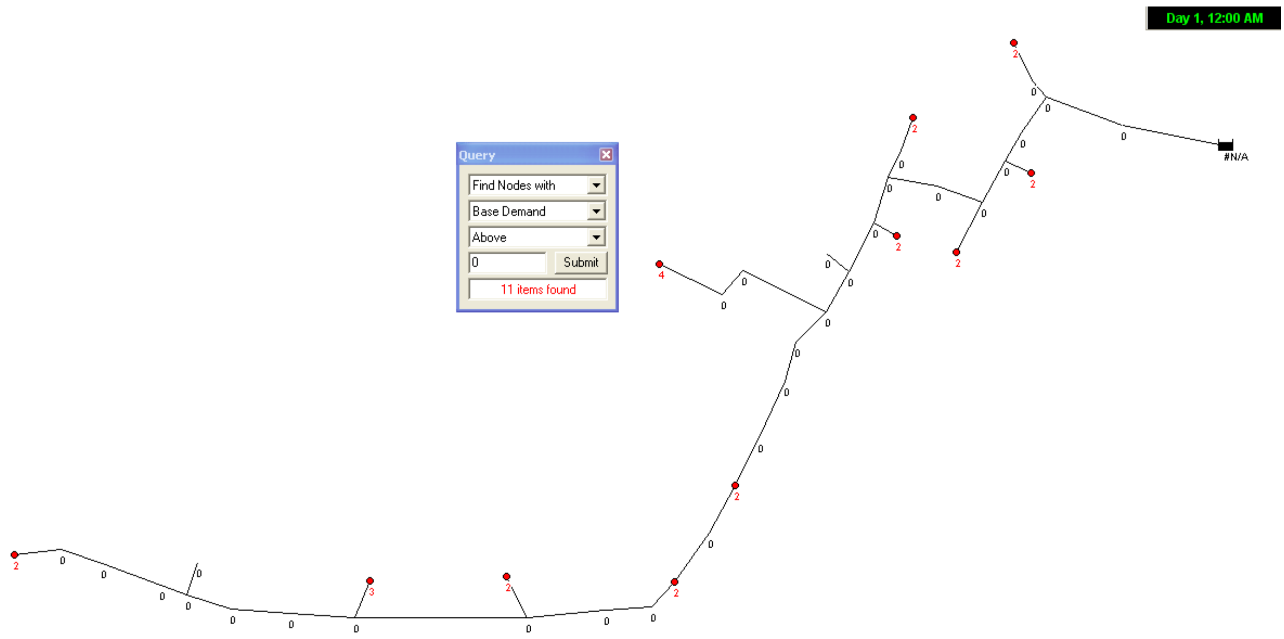


Figure C-7 Diversion K2 Demand Based on 50% Flow – Option 3

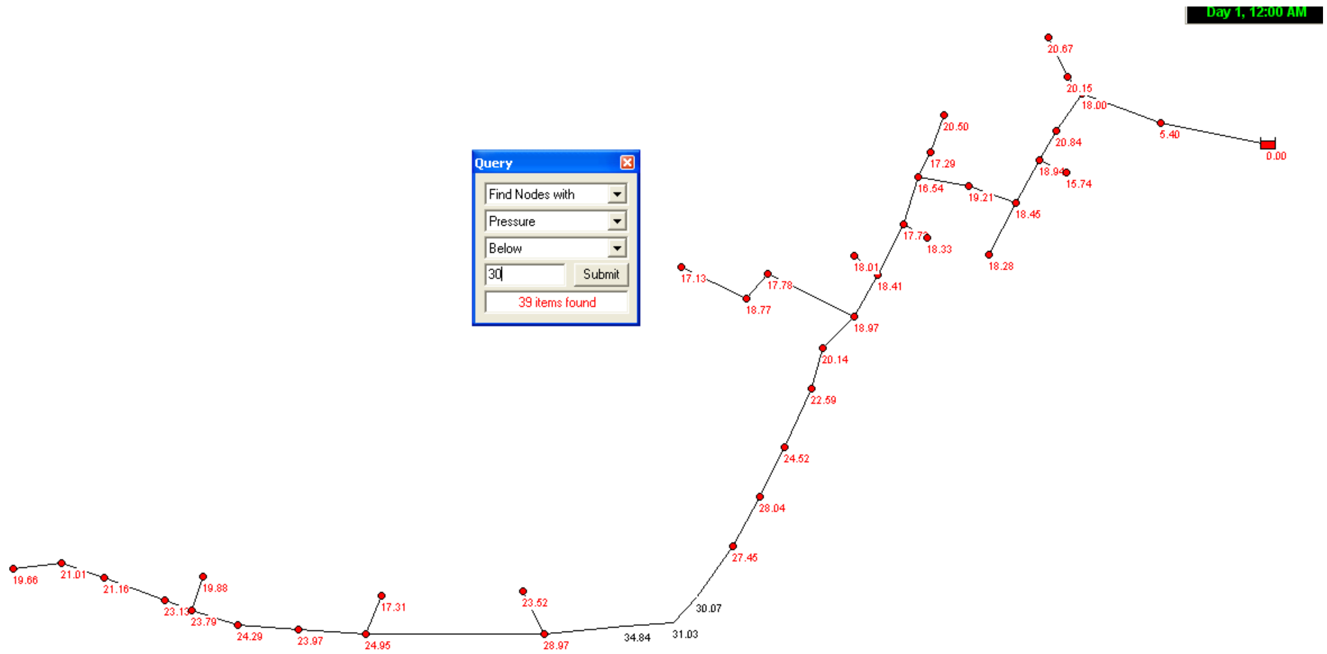


Figure C-8 Diversion K2 Demand Based on 50% Flow – Option 1 – Nodes with Pressure below 30m

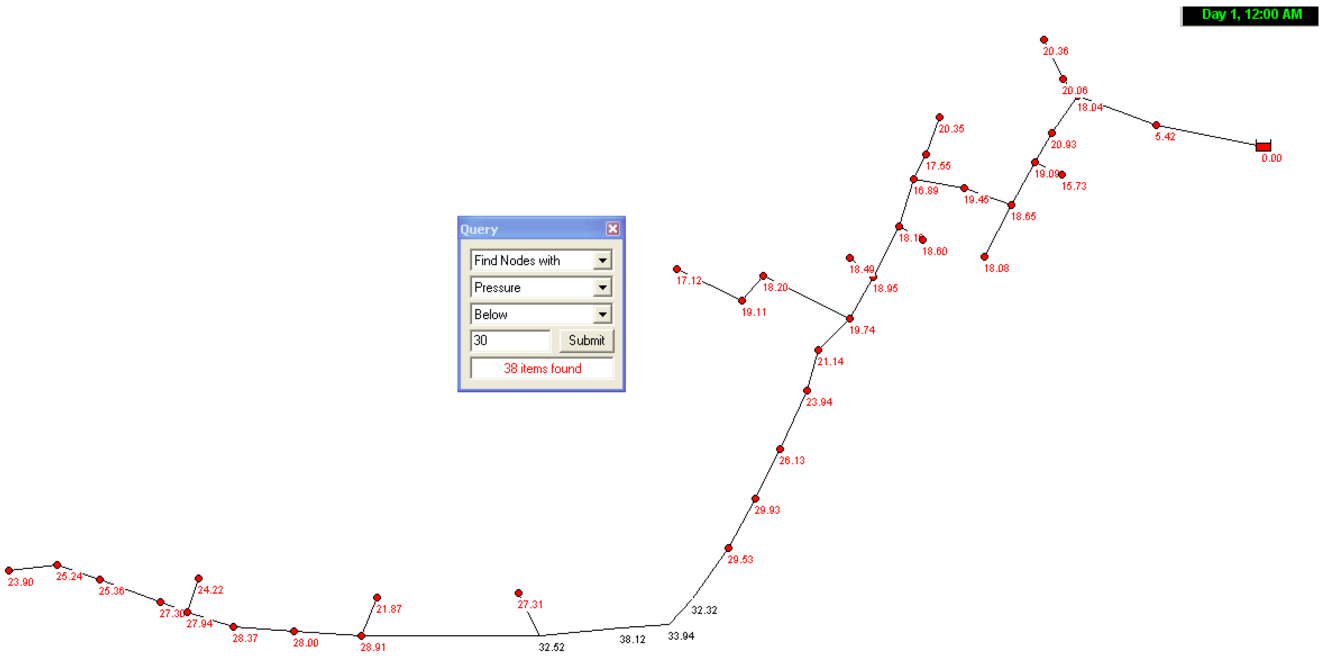


Figure C-9 Diversion K2 Demand Based on 50% Flow – Option 2 – Nodes with Pressure below **30m**

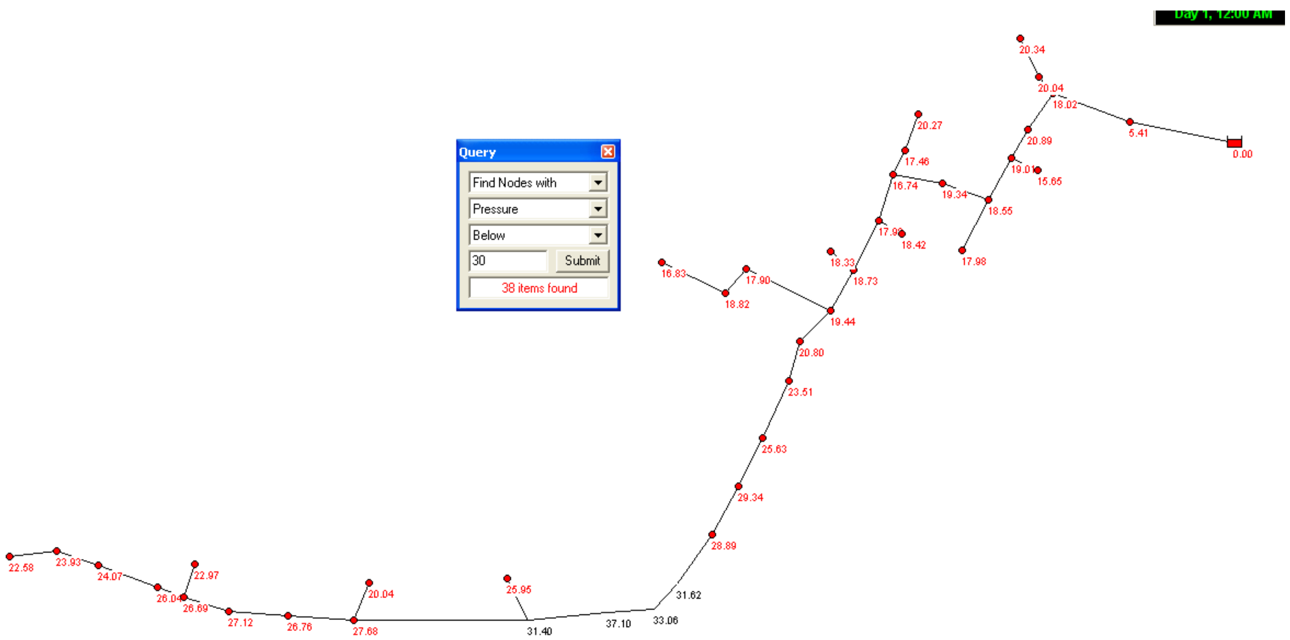


Figure C-10 Diversion K2 Demand Based on 50% Flow – Option 3 – Nodes with Pressure below 30m

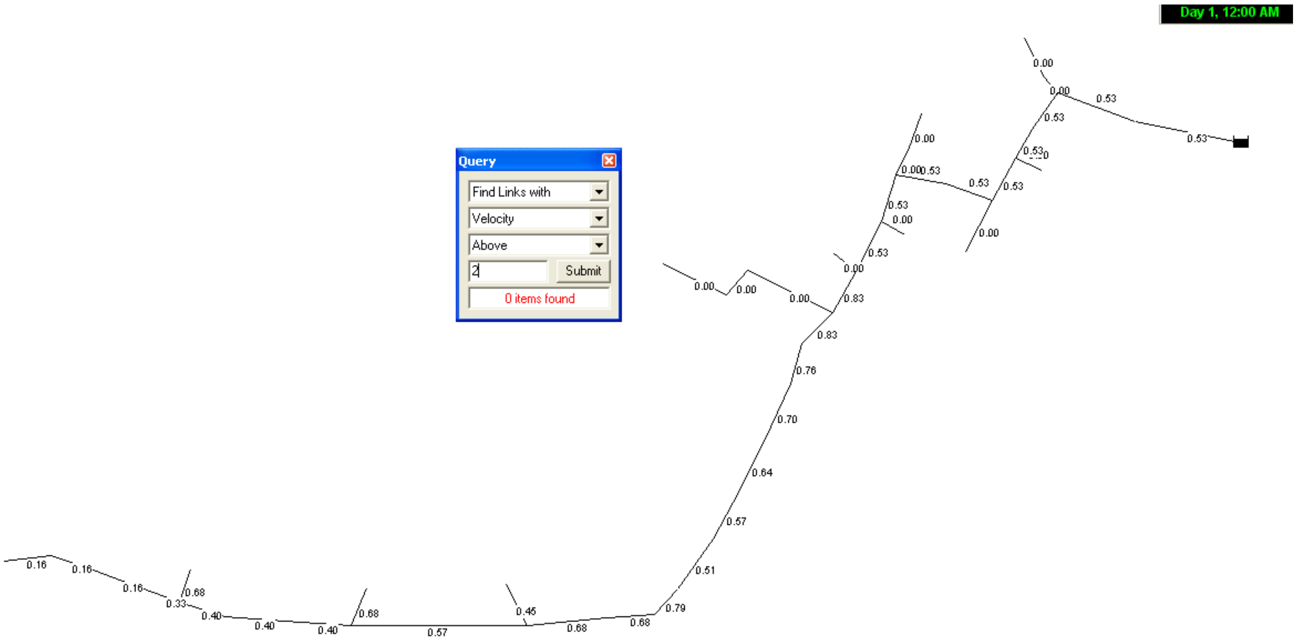


Figure C-11 Diversion K2 Demand Based on 50% Flow – Option 1 – Pipes with Velocity above 2m/s

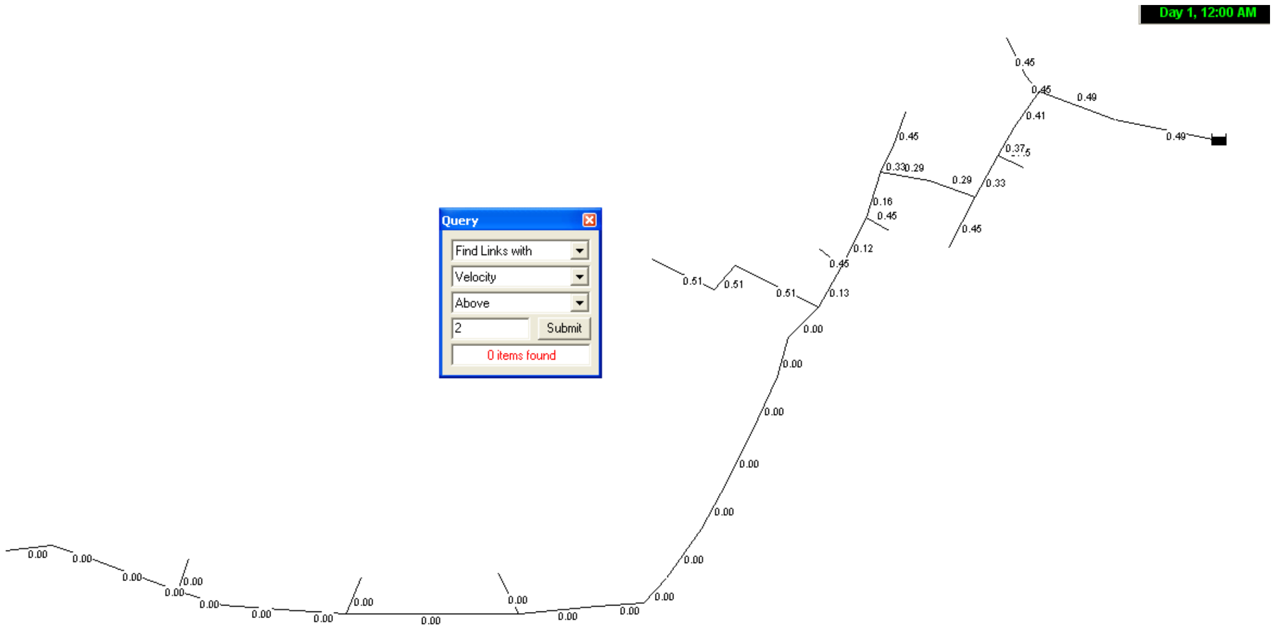


Figure C-12 Diversion K2 Demand Based on 50% Flow – Option 2 – Pipes with Velocity above 2m/s

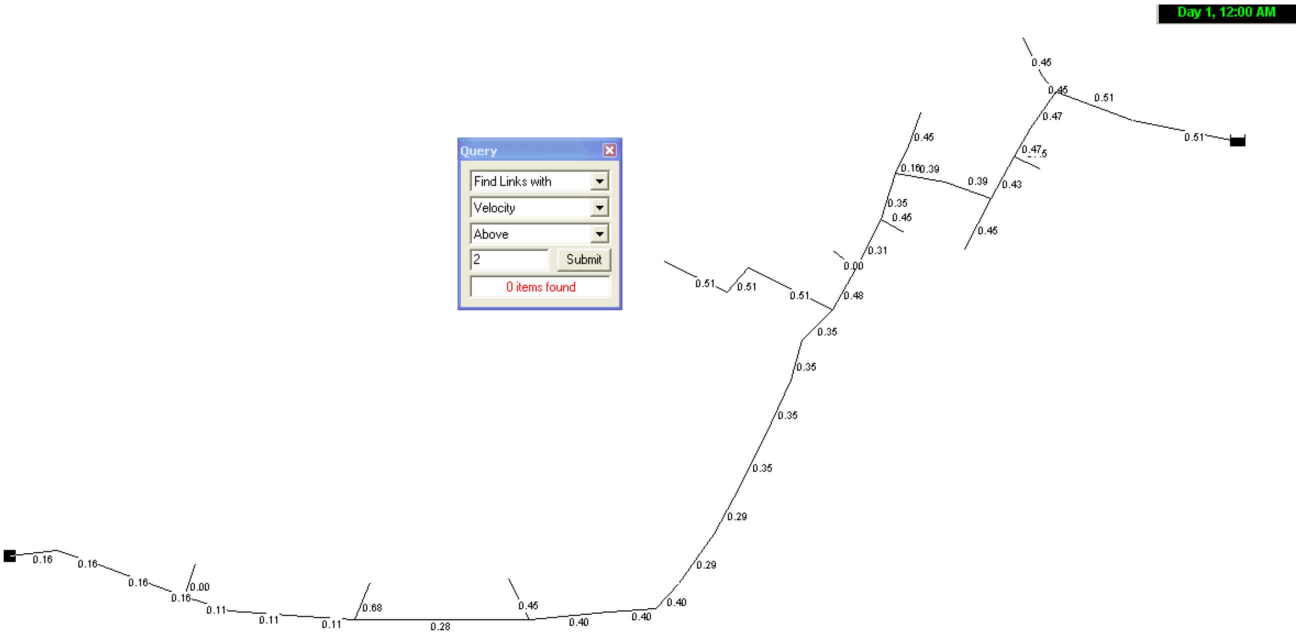


Figure C-13 Diversion K2 Demand Based on 50% Flow – Option 3 – Pipes with Velocity above 2m/s

K2-75%-Options 1, 2 & 3

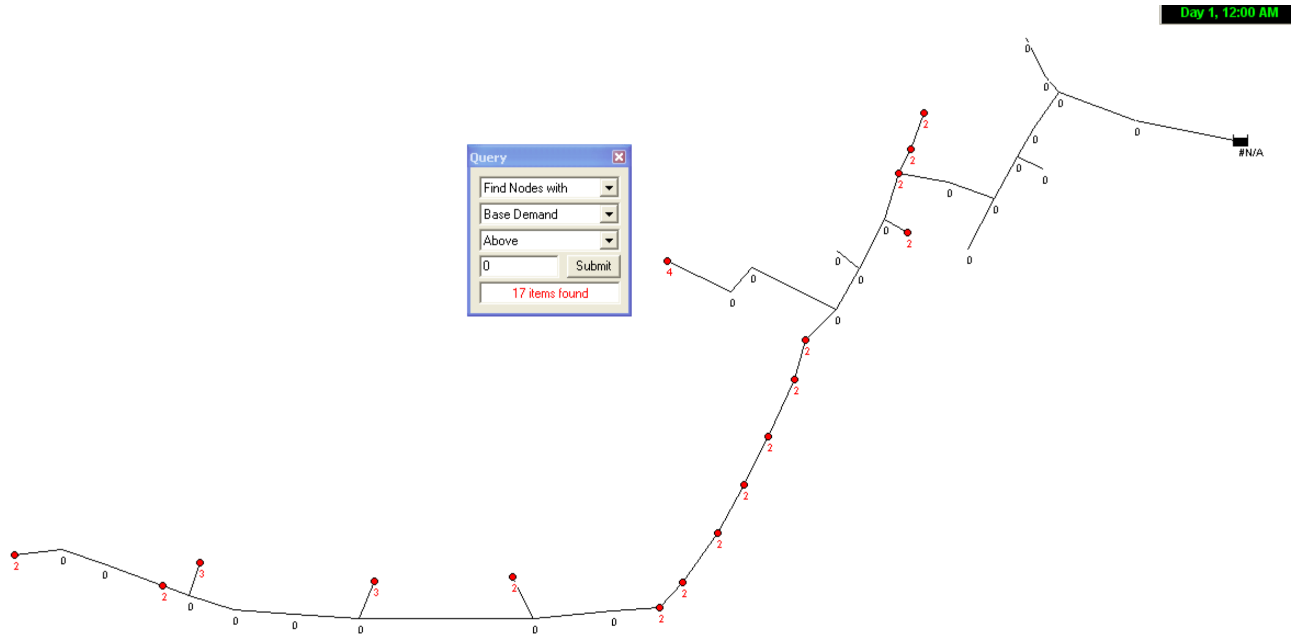


Figure C-14 Diversion K2 Demand Based on 75% Flow – Option 1

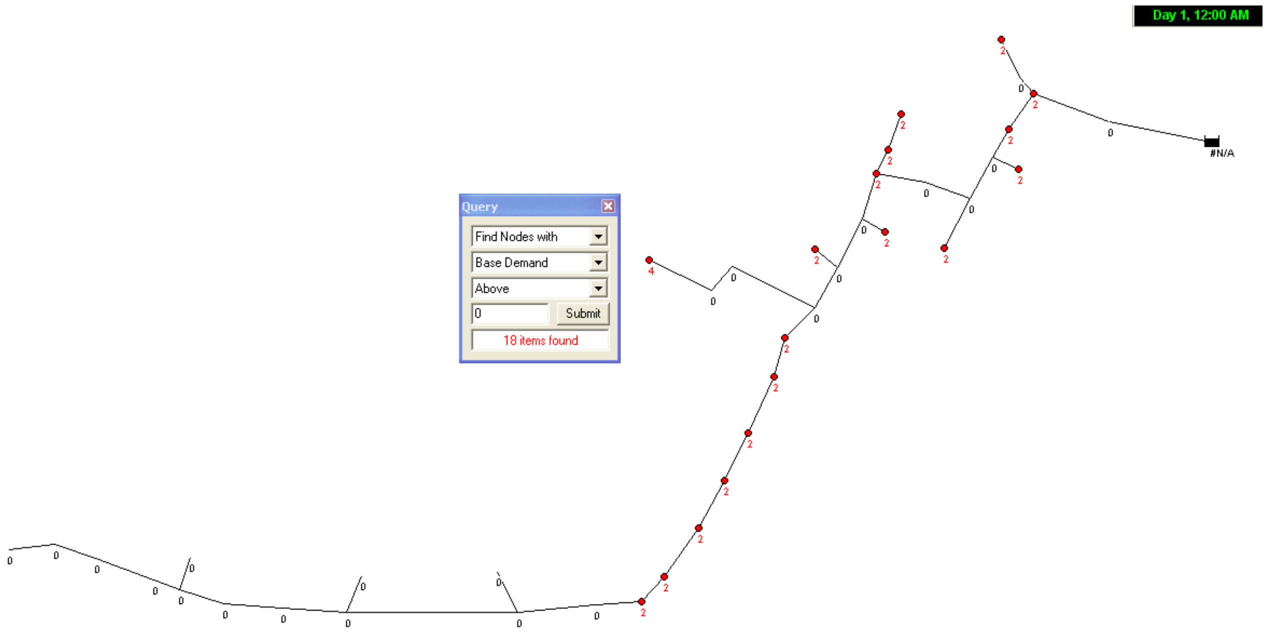


Figure C-15 Diversion K2 Demand Based on 75% Flow – Option 2

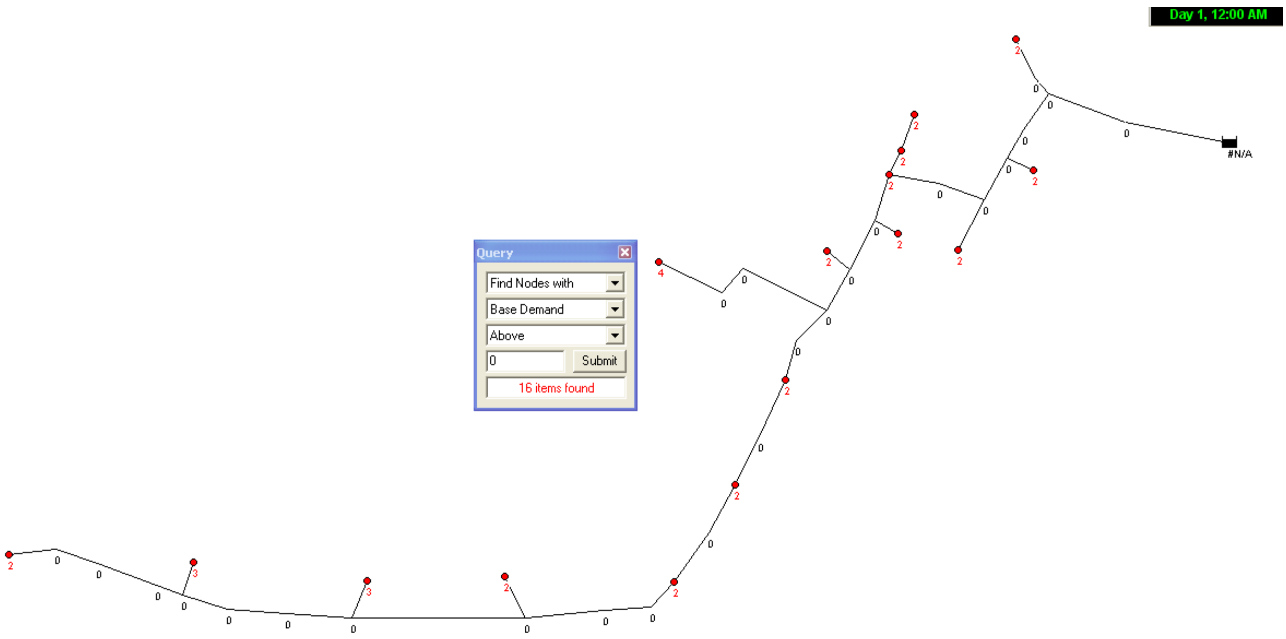


Figure C-16 Diversion K2 Demand Based on 75% Flow – Option 3

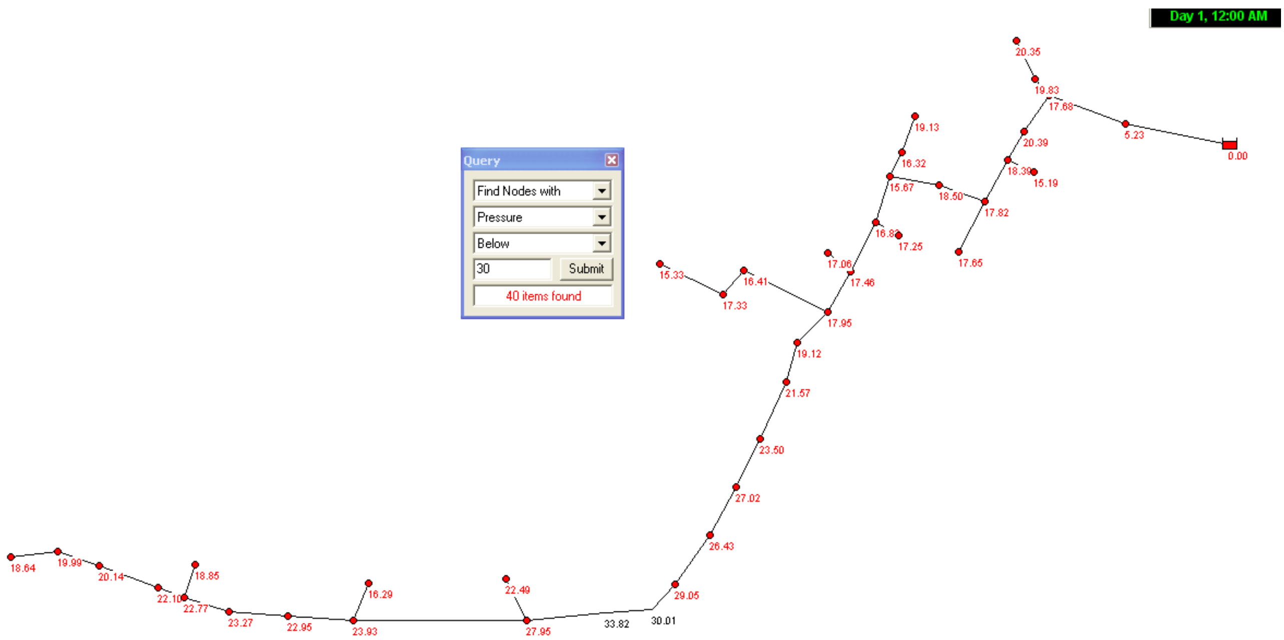


Figure C-17 Diversion K2 Demand Based on 75% Flow – Option 1 – Nodes with Pressure below 30m

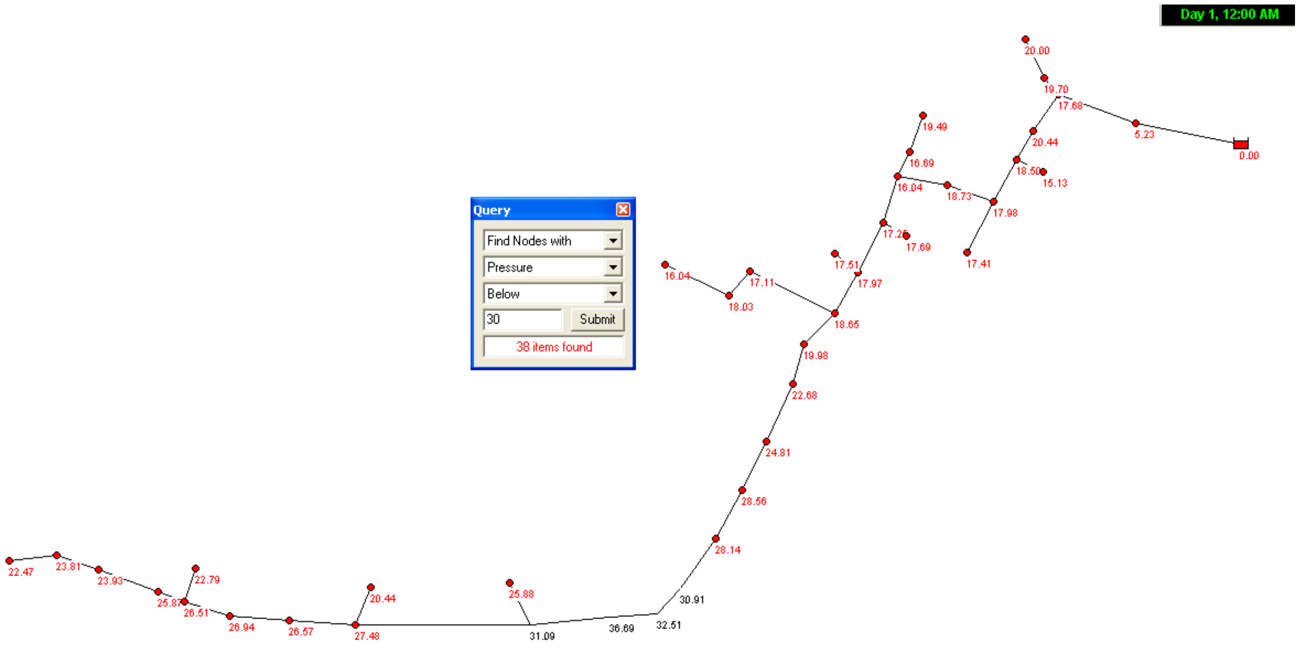


Figure C-18 Diversion K2 Demand Based on 75% Flow – Option 2 – Nodes with Pressure below 30m

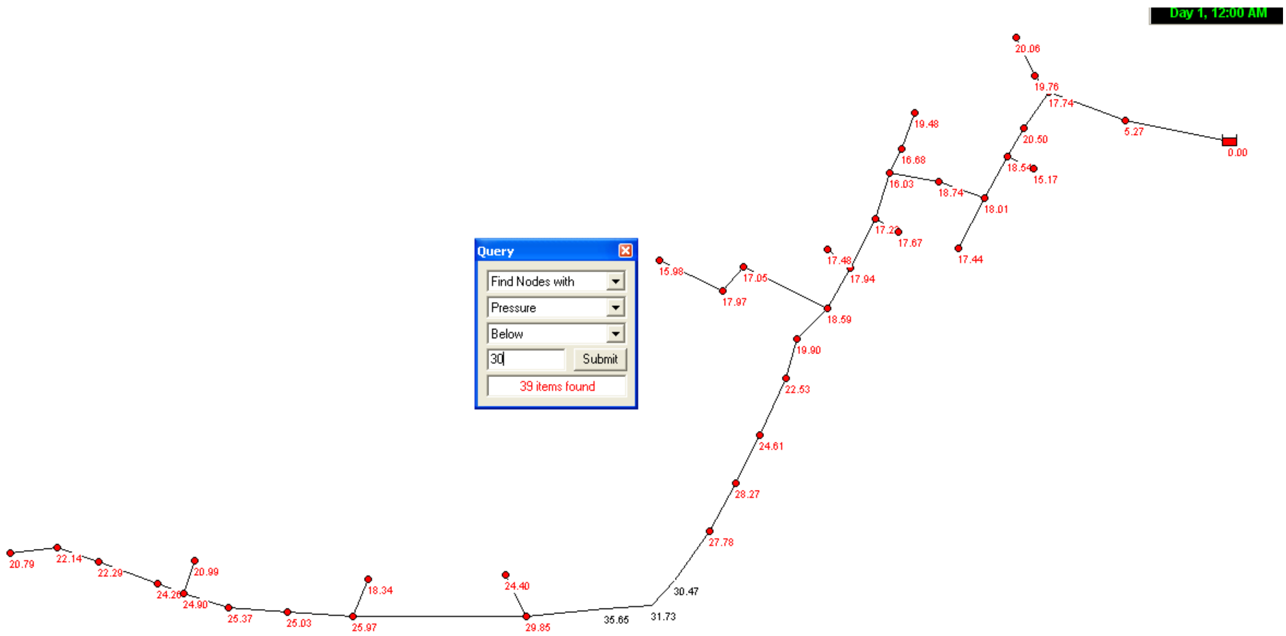


Figure C-19 Diversion K2 Demand Based on 75% Flow – Option 3 – Nodes with Pressure below 30m

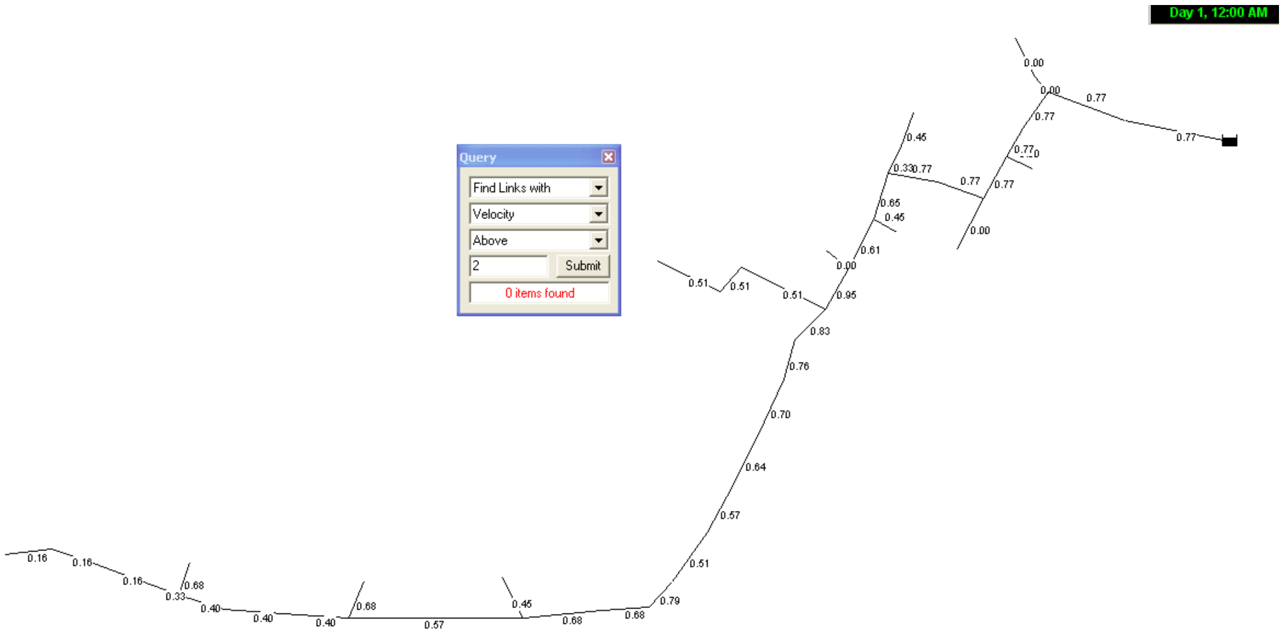


Figure C-20 Diversion K2 Demand Based on 75% Flow – Option 1 – Pipes with Velocity above 2m/s

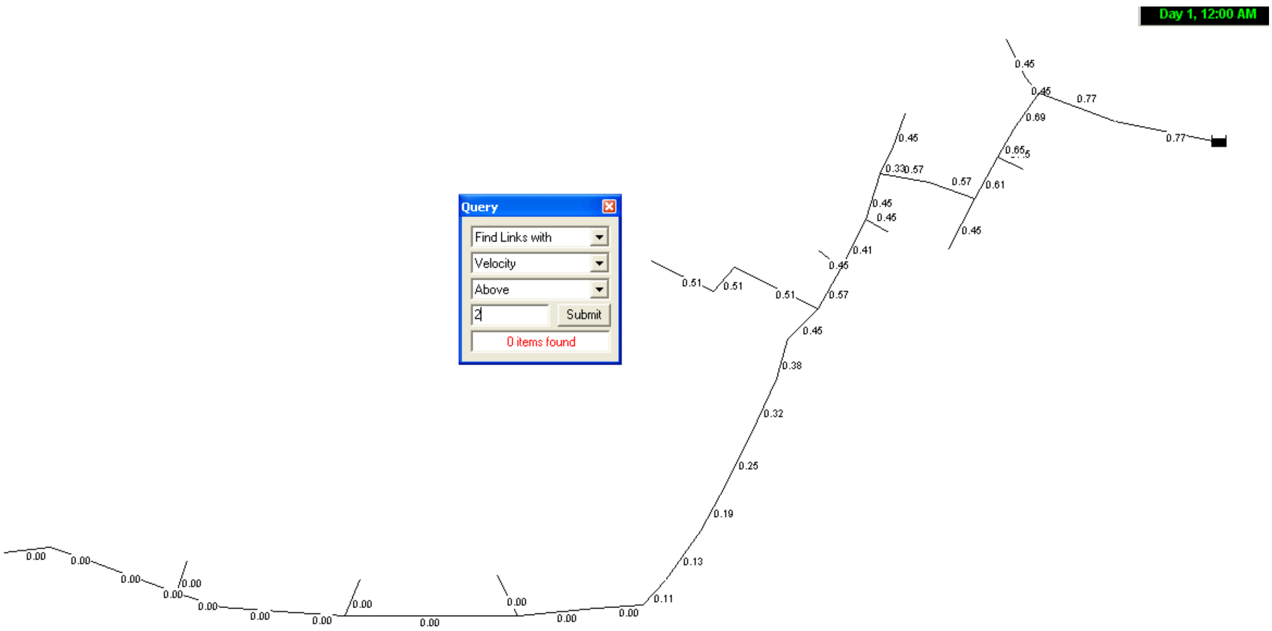


Figure C-21 Diversion K2 Demand Based on 75% Flow – Option 2 – Pipes with Velocity above 2m/s

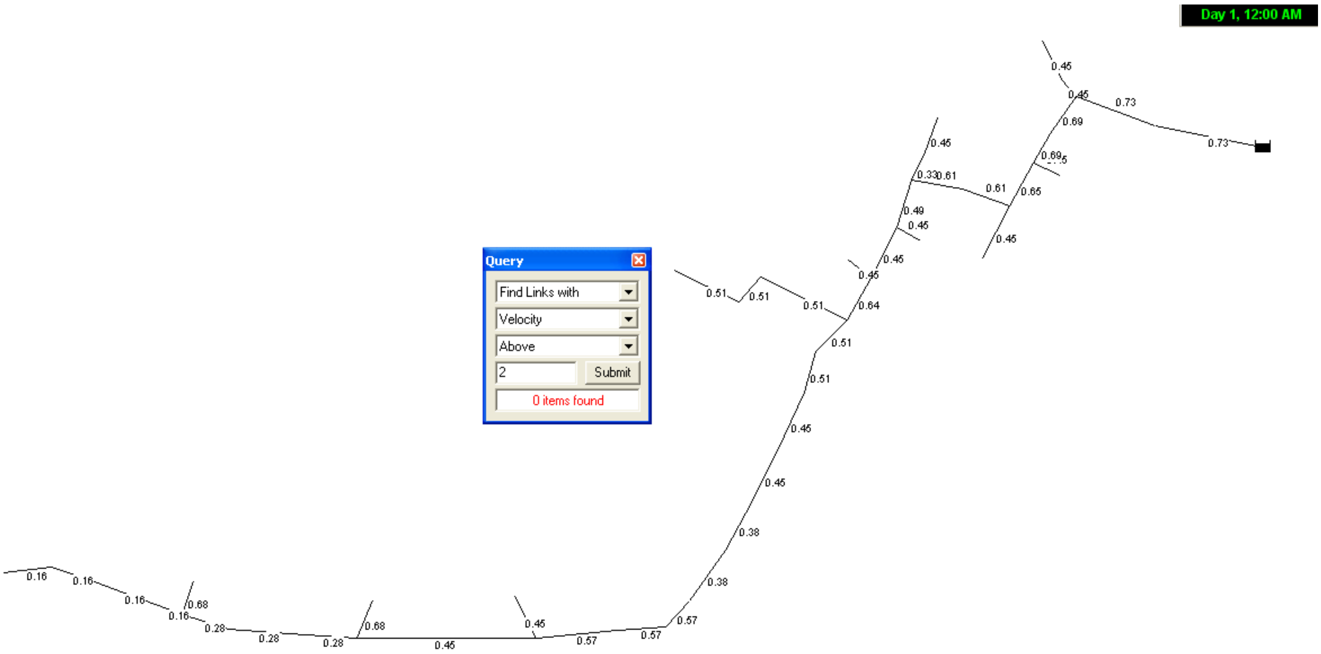


Figure C-22 Diversion K2 Demand Based on 75% Flow – Option 3 – Pipes with Velocity above 2m/s

APPENDIX D Simulation of Joub Jannine diversion based on percentage of design flow

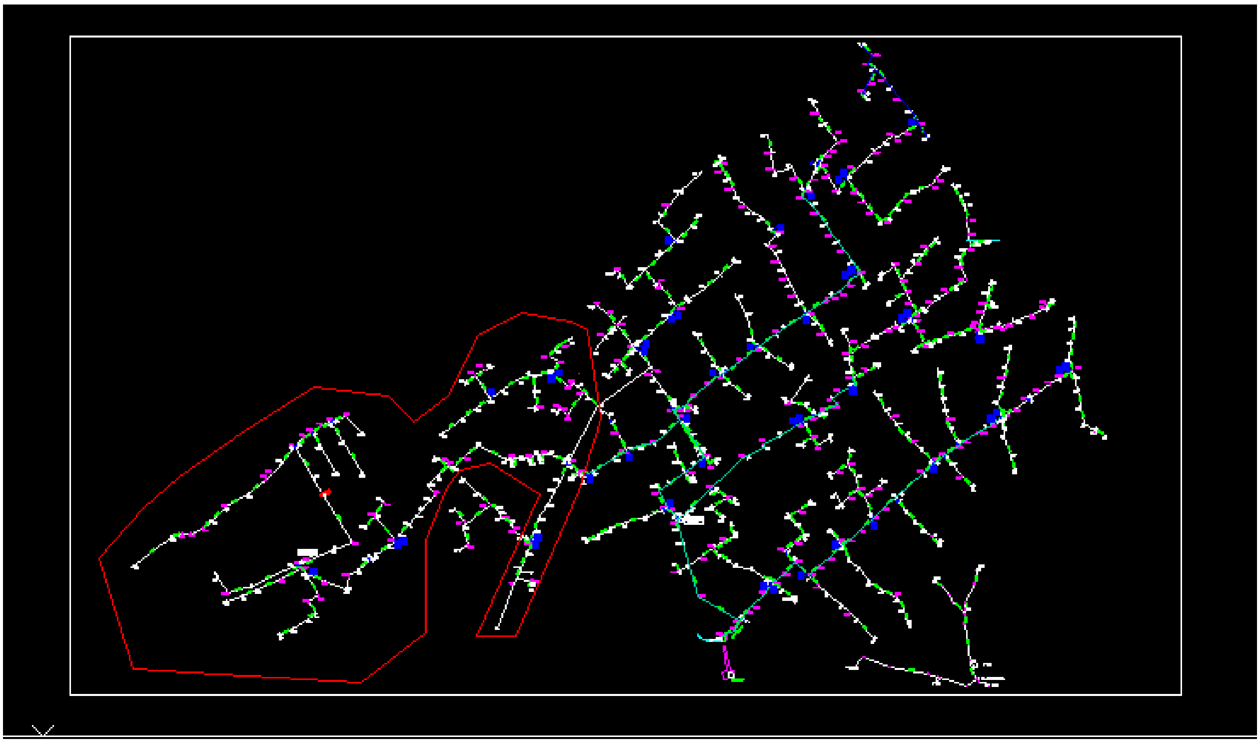


Figure D-1 JJ Diversions

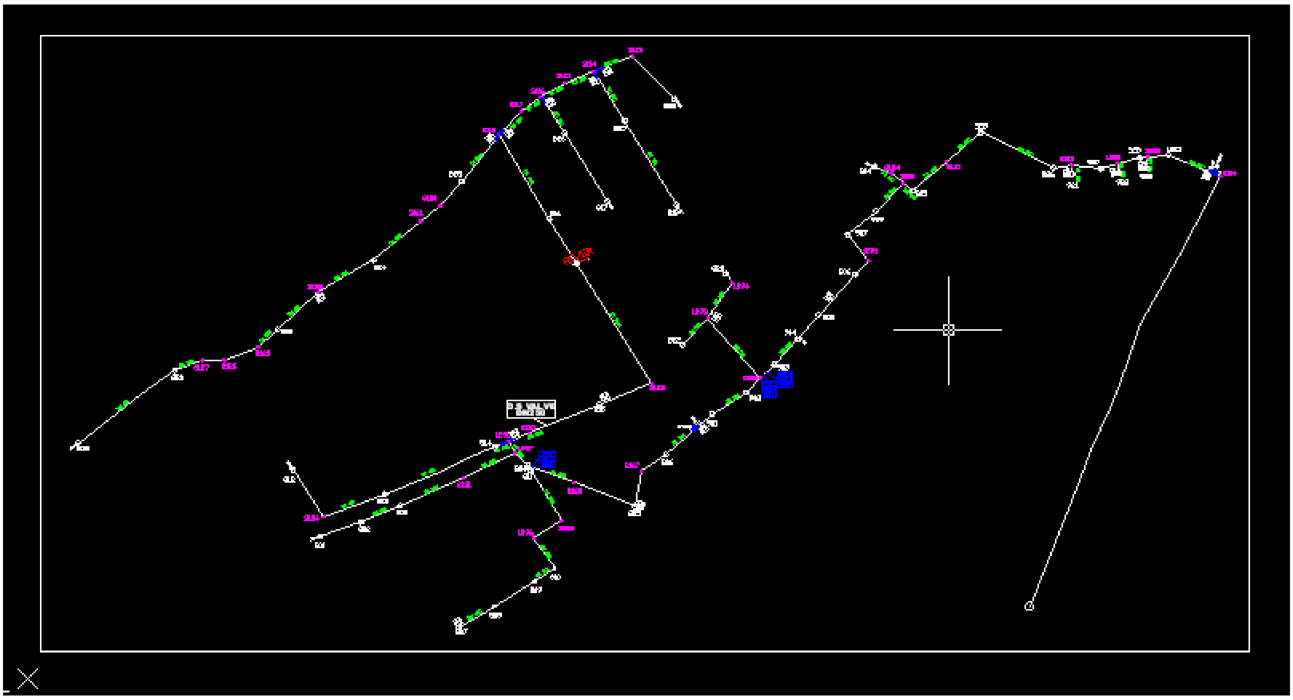


Figure D-2 Diversion JJ1

Table 2 Diversion JJ1 Flow Repartition

JJ-Diversion							
JJ1							
Node	Demand	50%			25%		
		O1	O2	O3	O1	O2	O3
901	8.4		8.4			8.4	
902	6.3		6.3	6.3			
903	8.4		8.4			8.4	
904	8.4		8.4	8.4			
905	9.7		9.7			9.7	
906	9.7		9.7	9.7			
907	4.2		4.2			4.2	
909	9.7		9.7	9.7			
914	6.2		6.2	6.2		6.2	6.2
915	4.2		4.2			4.2	
921	8.4		8.4	8.4		8.4	8.4
922	4.2		4.2	4.2		4.2	4.2
923	4.2		4.2	4.2		4.2	4.2
925	6.3		6.3				
926	6.3		6.3			6.3	
927	4.2		4.2				
928	4.2		4.2			4.2	
1005	8.4		8.4				
822	13.8		13.8	13.8		13.8	13.8
823	2.1		2.1	2.1		2.1	2.1
801	6.3	6.3		6.3	6.3		6.3
802	4.2	4.2					
803	6.3	6.3					
804	4.2	4.2			4.2		
805	6.3		6.3			6.3	
806	10.5		10.5	10.5			
807	8.4		8.4	8.4		8.4	8.4
808	9.7		9.7				
809	9.7		9.7	9.7			
810	6.3		6.3				
811	6.3		6.3	6.3		6.3	6.3
812	13.8	13.8		13.8	13.8		13.8
813	20.6	20.6					
814	20.6	20.6			20.6		
815	20.6	20.6		20.6			
816	5.5	5.5		5.5	5.5		5.5
817	5.5	5.5		5.5	5.5		5.5
818	11	11		11	11		11

JJ-Diversion							
JJ1							
Node	Demand	50%			25%		
		O1	O2	O3	O1	O2	O3
819	5.5	5.5		5.5	5.5		5.5
820	13.8	13.8					
821	13.8	13.8			13.8		
824	13.8	13.8					
825	13.8	13.8		13.8	13.8		
826	8.4	8.4					
827	8.4	8.4					
828	4.2	4.2		4.2	4.2		4.2
Total	394.8	200.3	194.5	194.1	104.2	105.3	105.4
Percentage		50.7	49.3	49.2	26.4	26.7	26.7

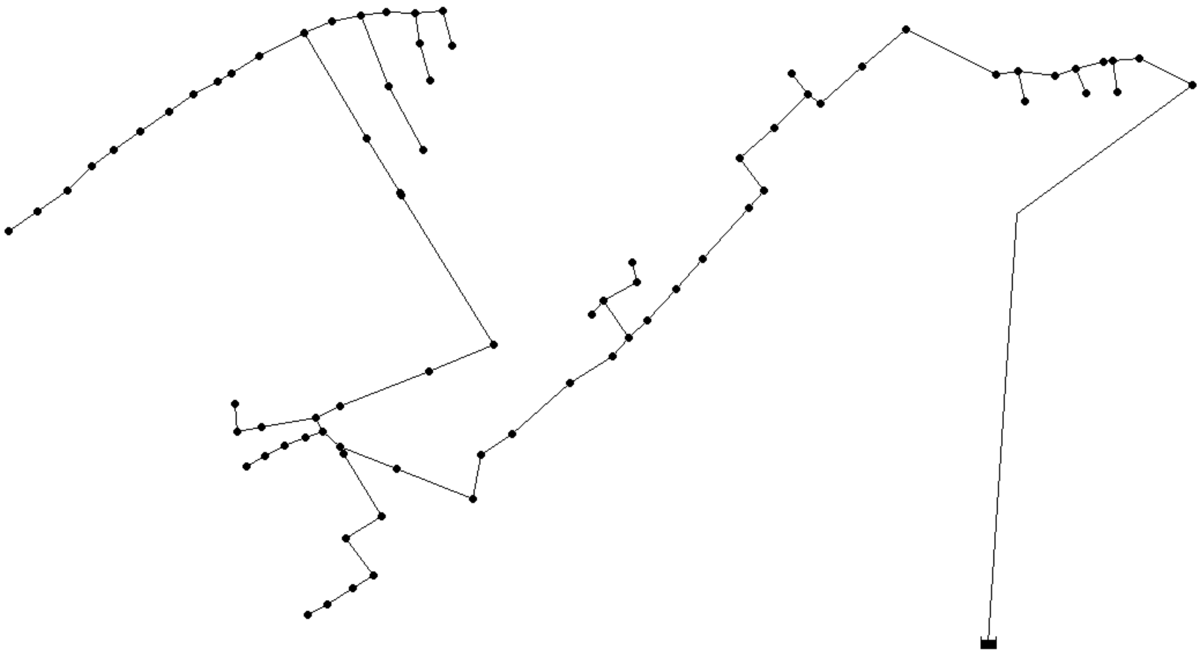


Figure D-3 Diversion JJ1 EpaNet Model

D1: JJ1-50%-Options 1, 2 & 3

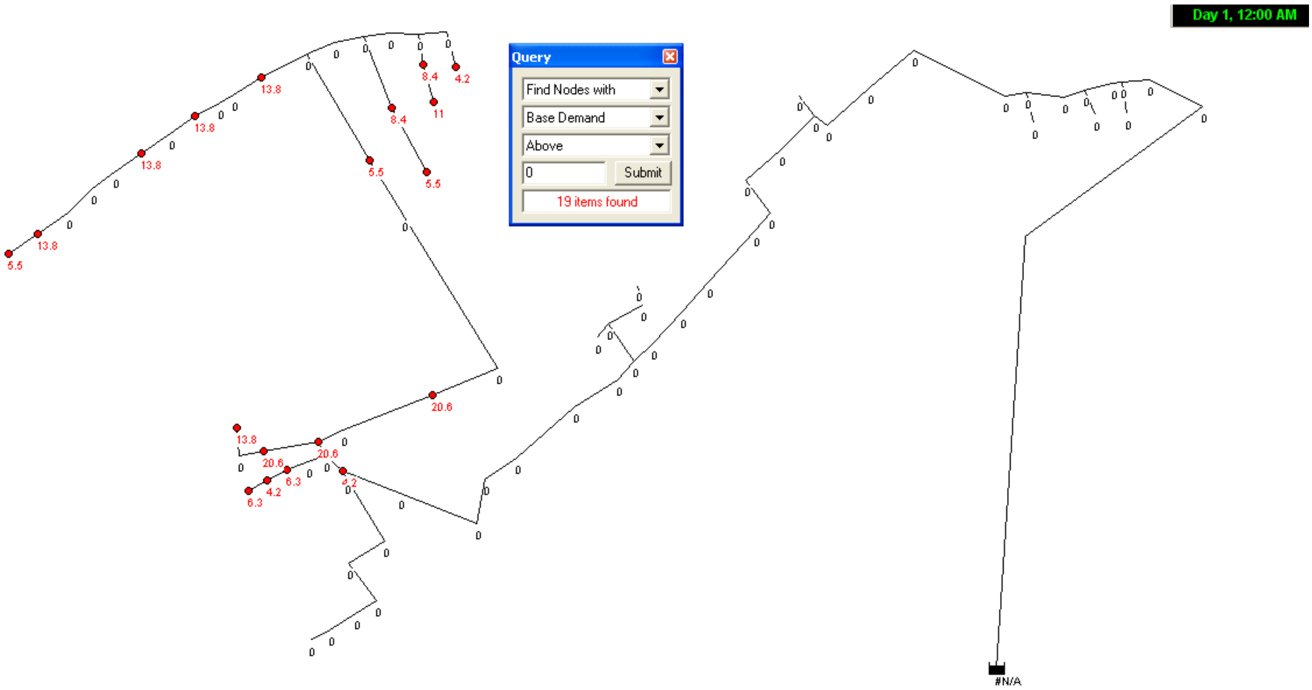


Figure D-4 Diversion JJ1 Demand Based on 50% Flow – Option 1

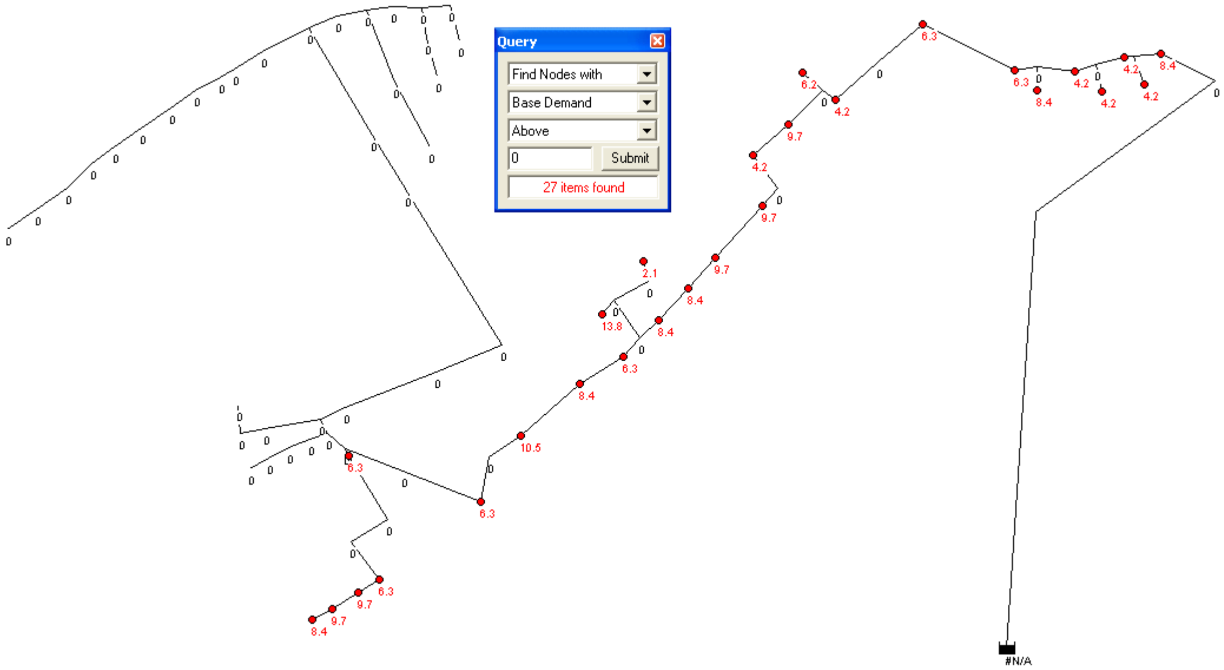


Figure D-5 Diversion JJ1 Demand Based on 50% Flow – Option 2

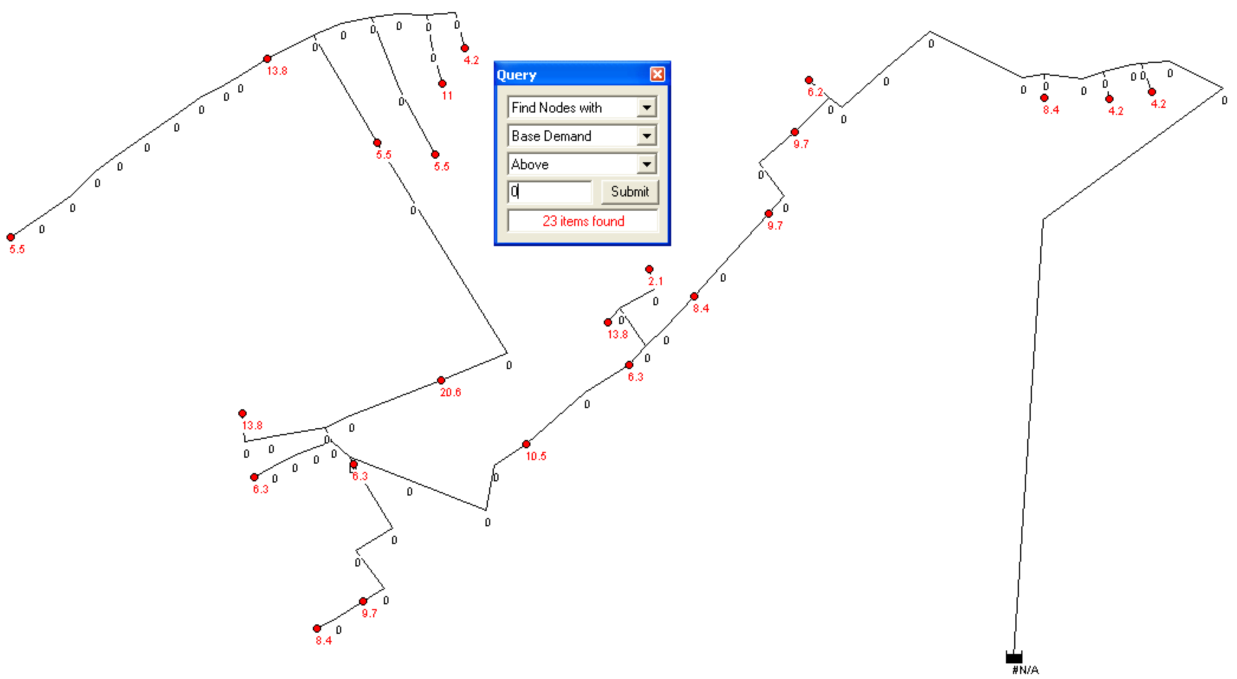


Figure D-6 Diversion JJ1 Demand Based on 50% Flow – Option 3

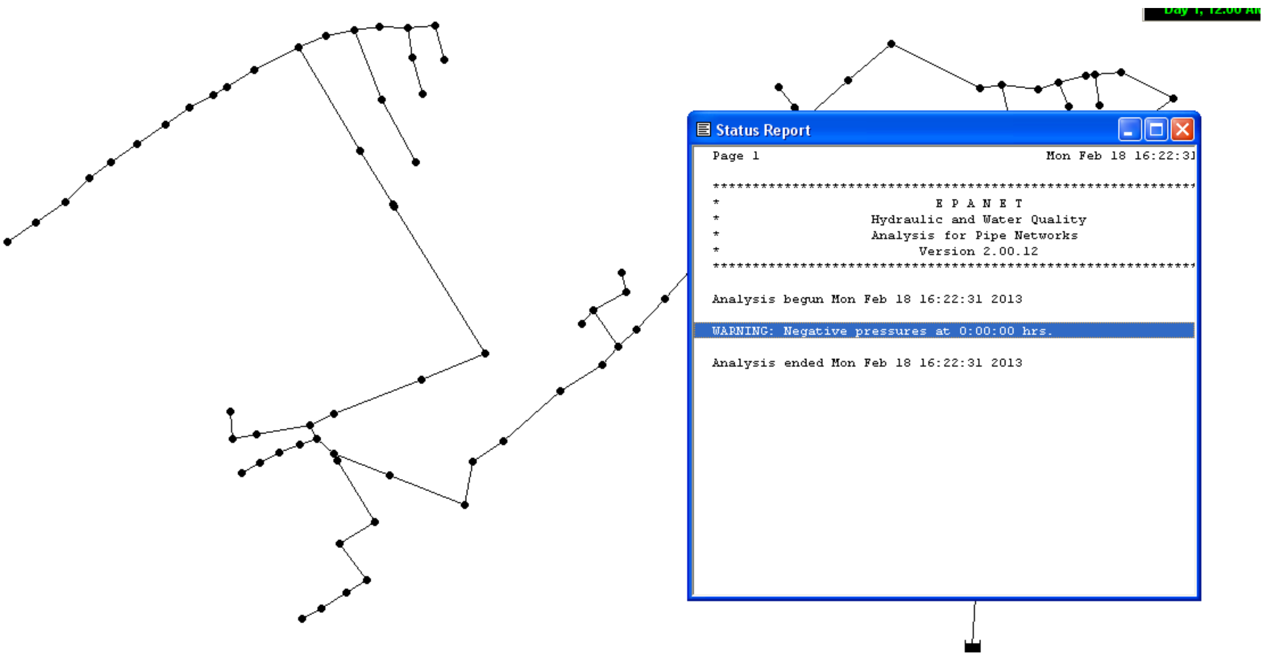


Figure D-7 Diversion JJ1 unsuccessful Simulation Report Based on 50% Flow Demand

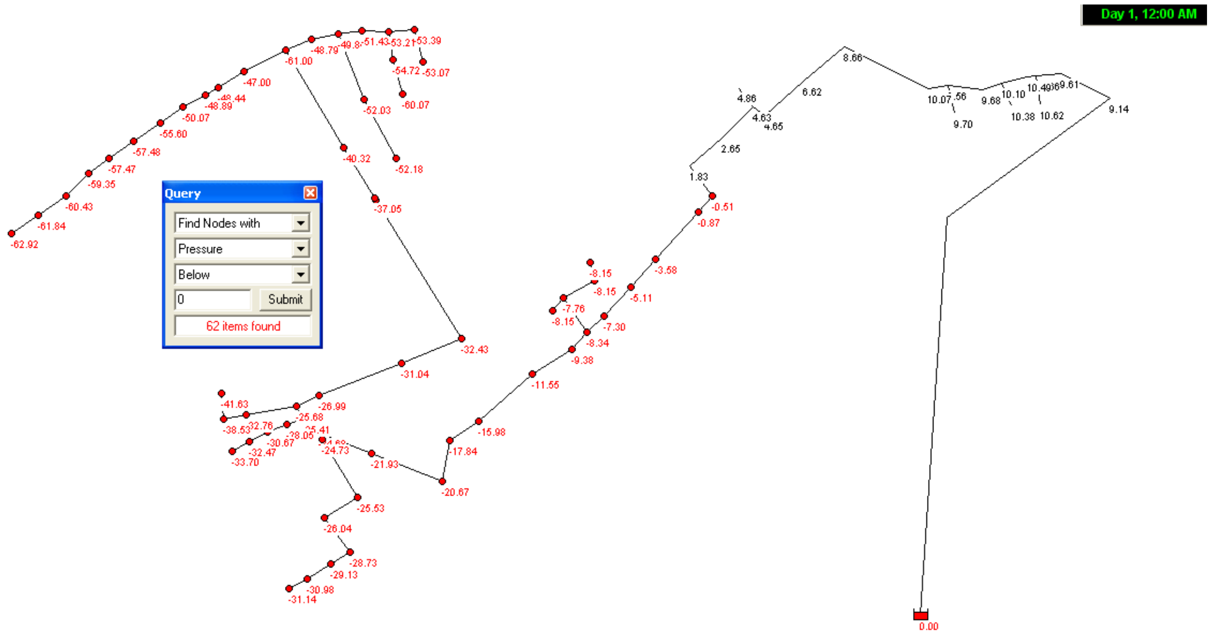


Figure D-8 Diversion JJ1 Demand Based on 50% Flow – Nodes with Negative Pressure

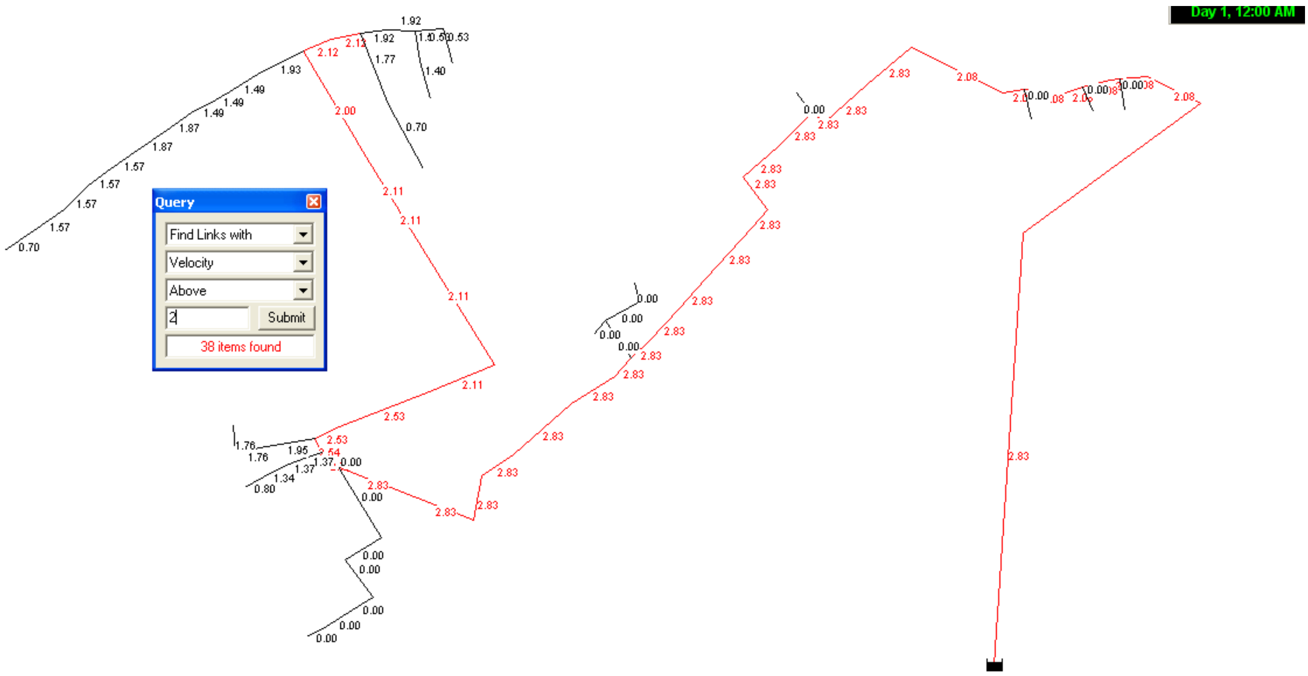


Figure D-9 Diversion JJ1 Demand Based on 50% Flow – Pipes with Velocity above 2m/s

D2: JJ1 25% - Options 1, 2 & 3

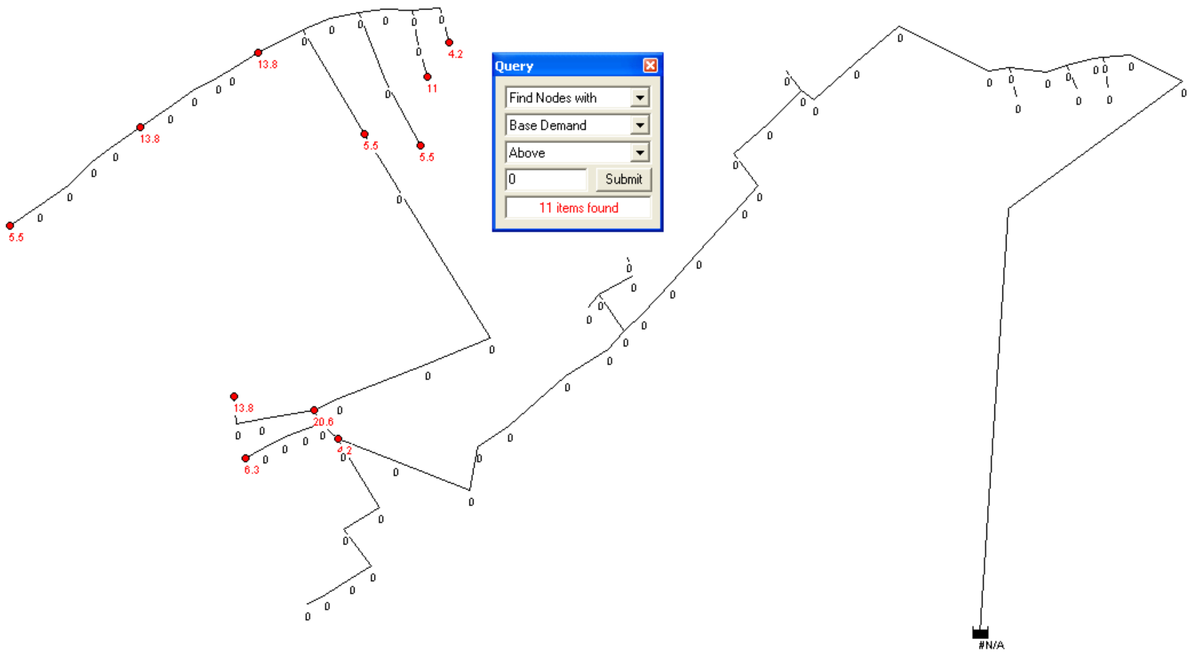


Figure D-10 Diversion JJ1 Demand Based on 25% flow – Option 1

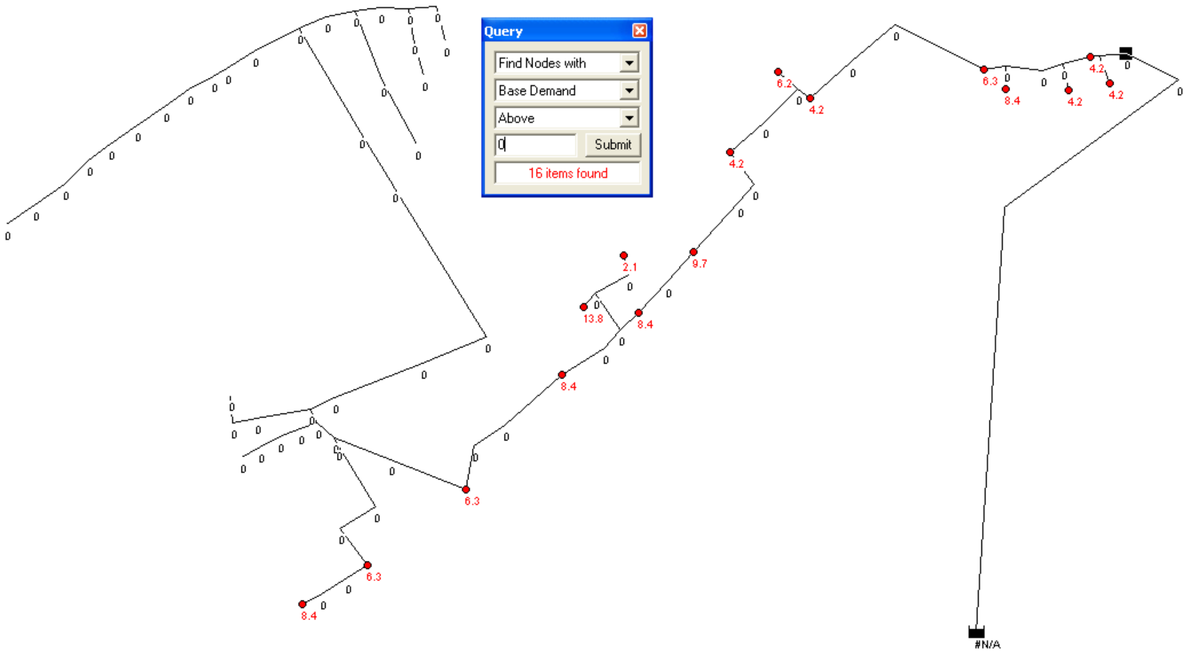


Figure D-11 Diversion JJ1 Demand Based on 25% flow – Option 2

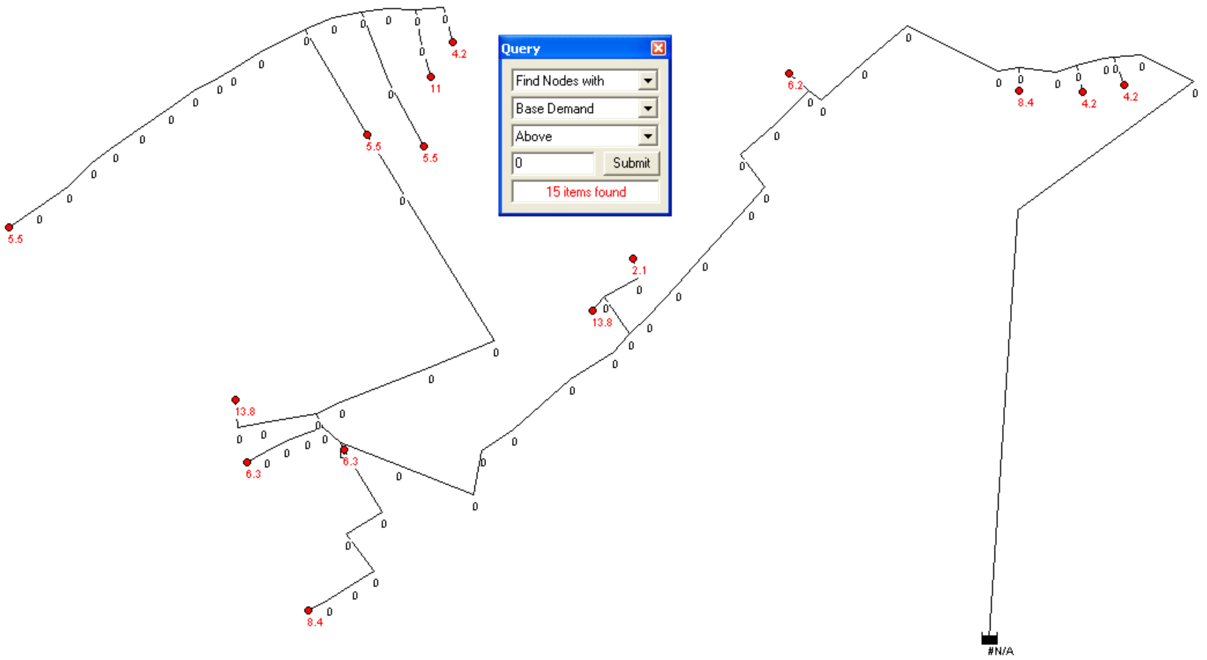


Figure D-12 Diversion JJ1 Demand Based on 25% flow – Option 3

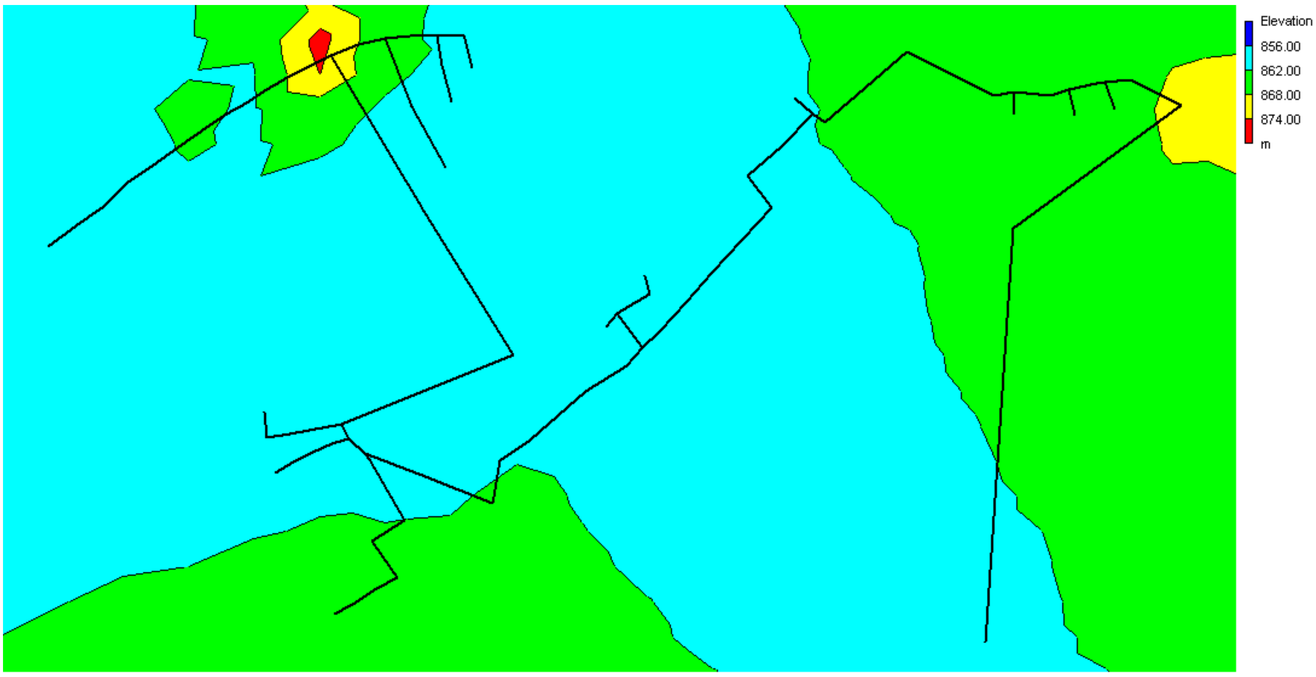


Figure D-13 Diversion JJ1 – Static Pressure Graph

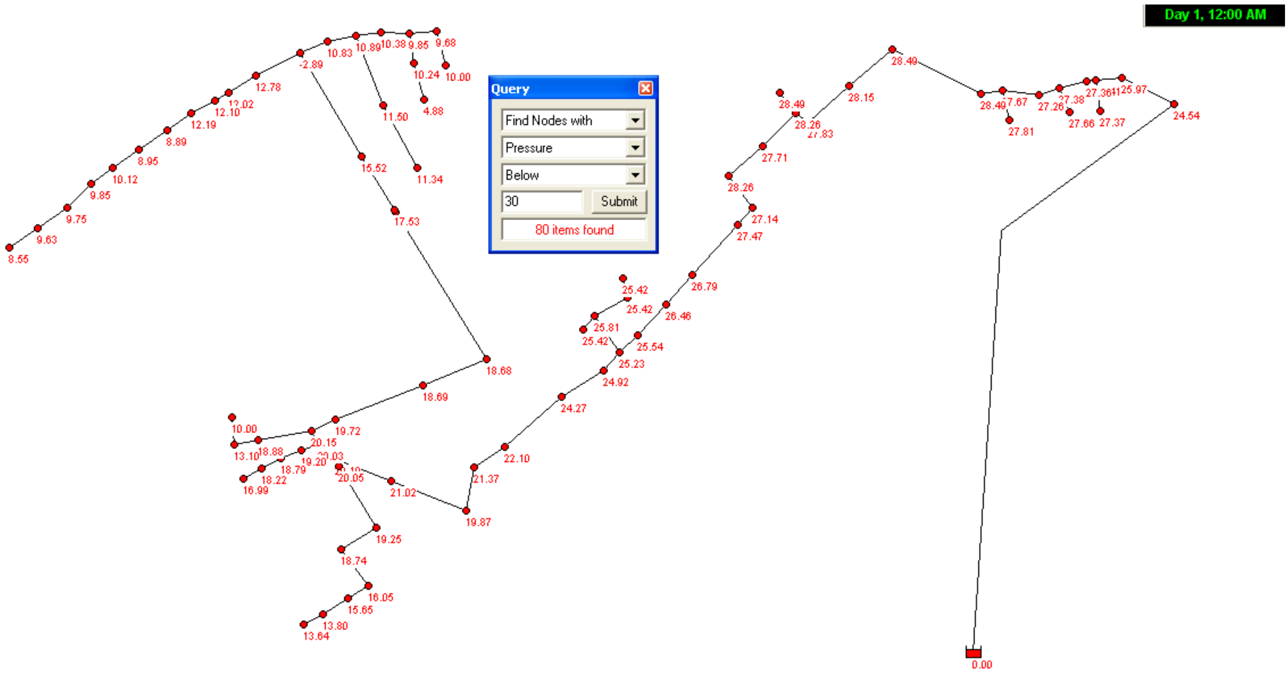


Figure D-14 Diversion JJ1 Demand Based on 25% flow – Option 1 – Pressure below 30m

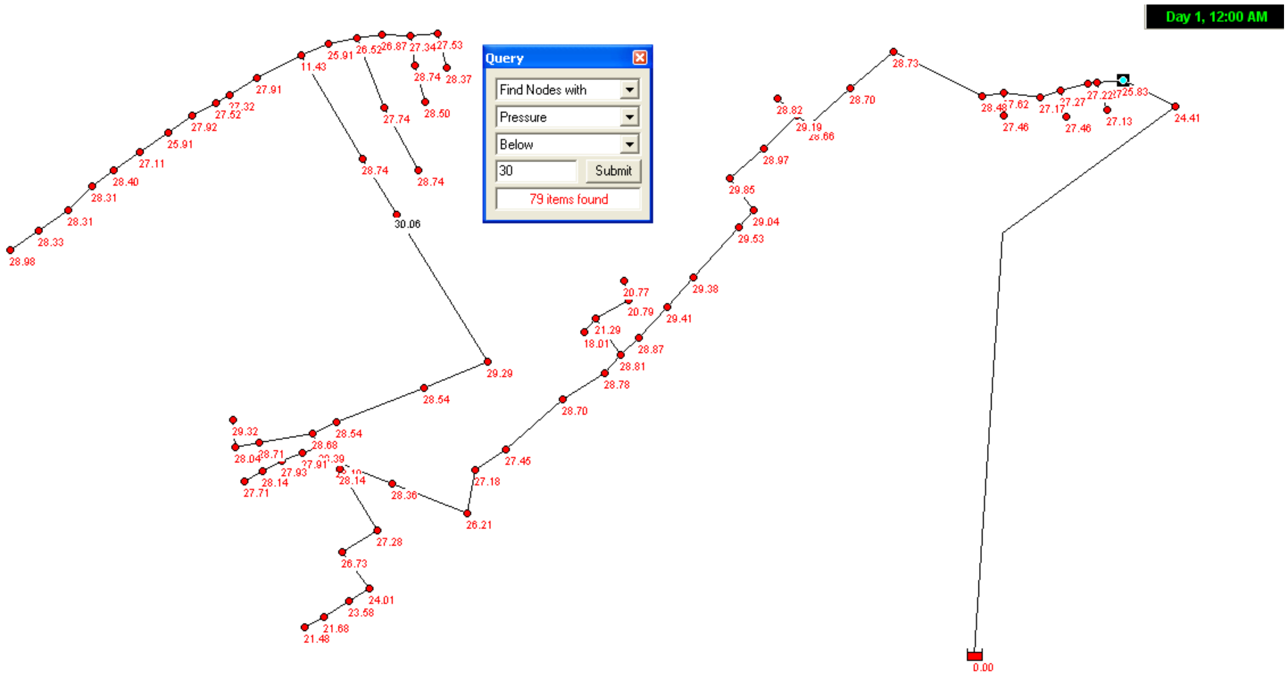


Figure D-15 Diversion JJ1 Demand Based on 25% flow – Option 2 – Pressure below 30m

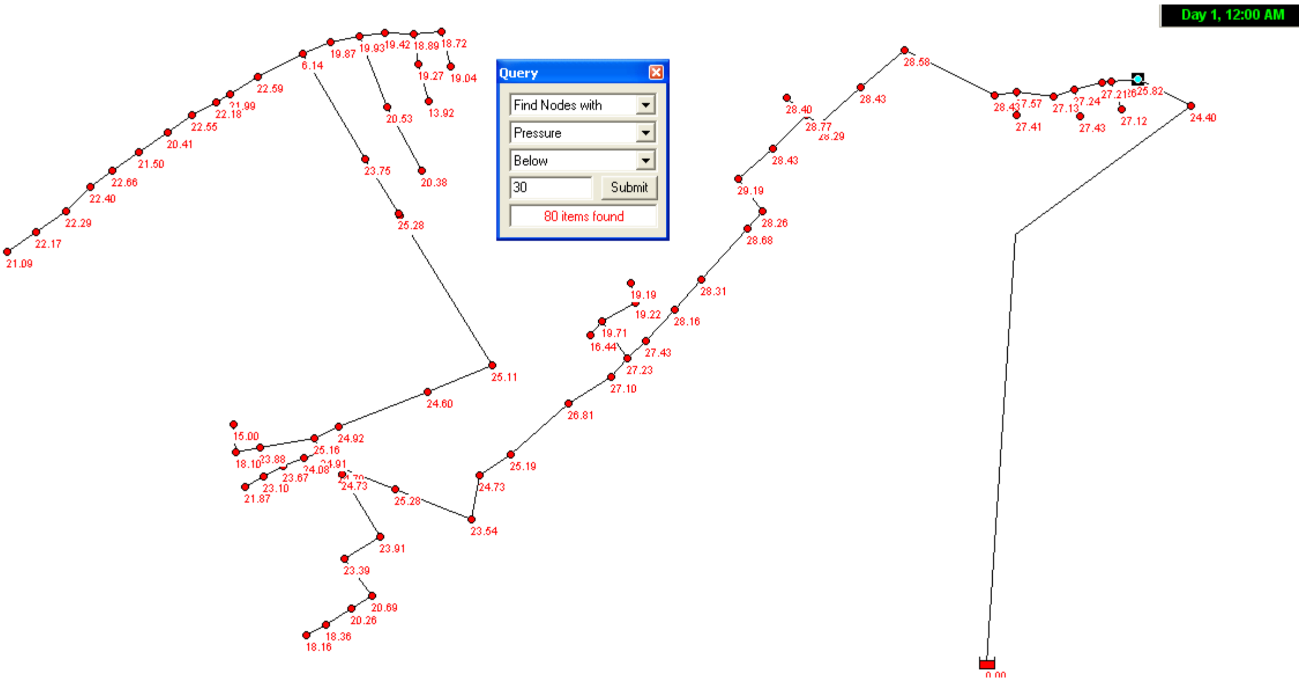


Figure D-16 Diversion JJ1 Demand Based on 25% flow – Option 3 – Pressure below 30m

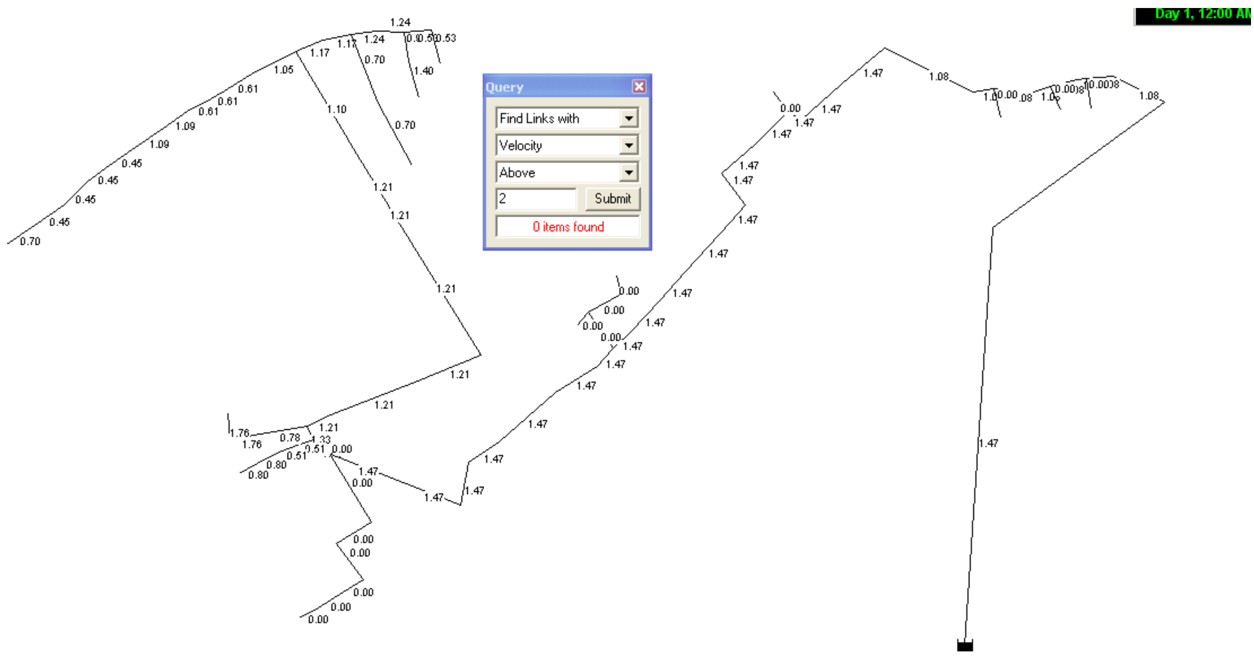


Figure D-17 Diversion JJ1 Demand Based on 25% flow – Option 1 – Velocity above 2m/s

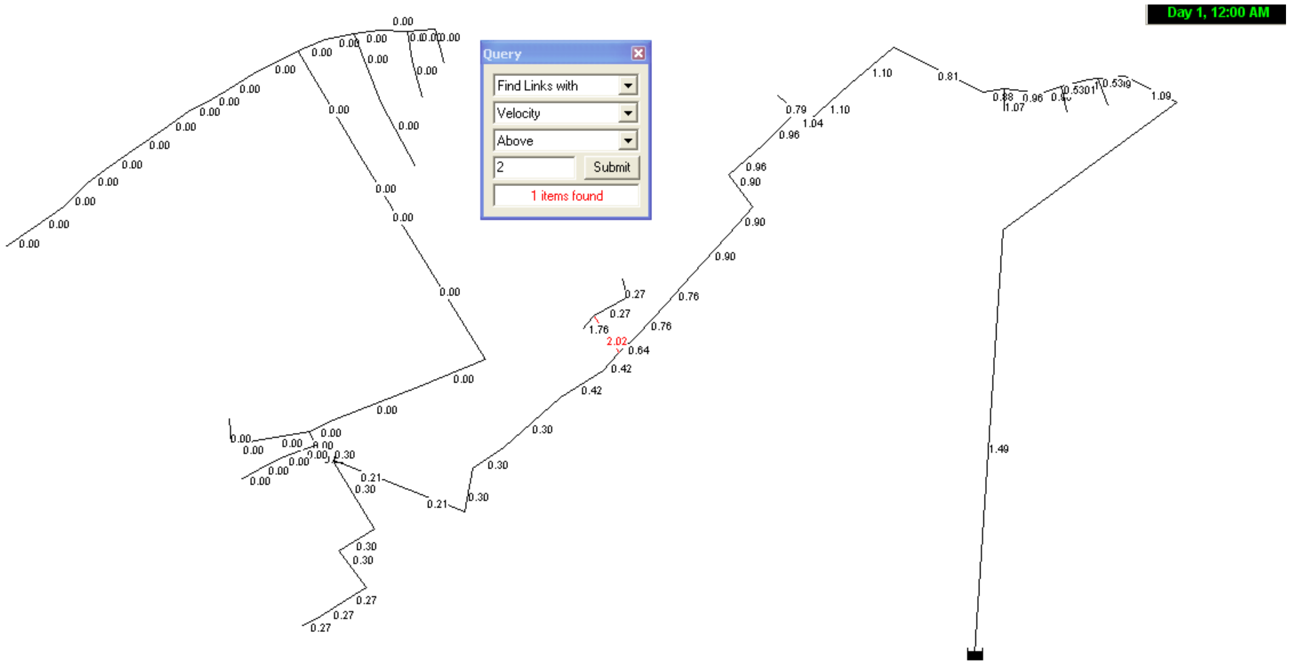


Figure D-18 Diversion JJ1 Demand Based on 25% flow – Option 2 – Velocity above 2m/s

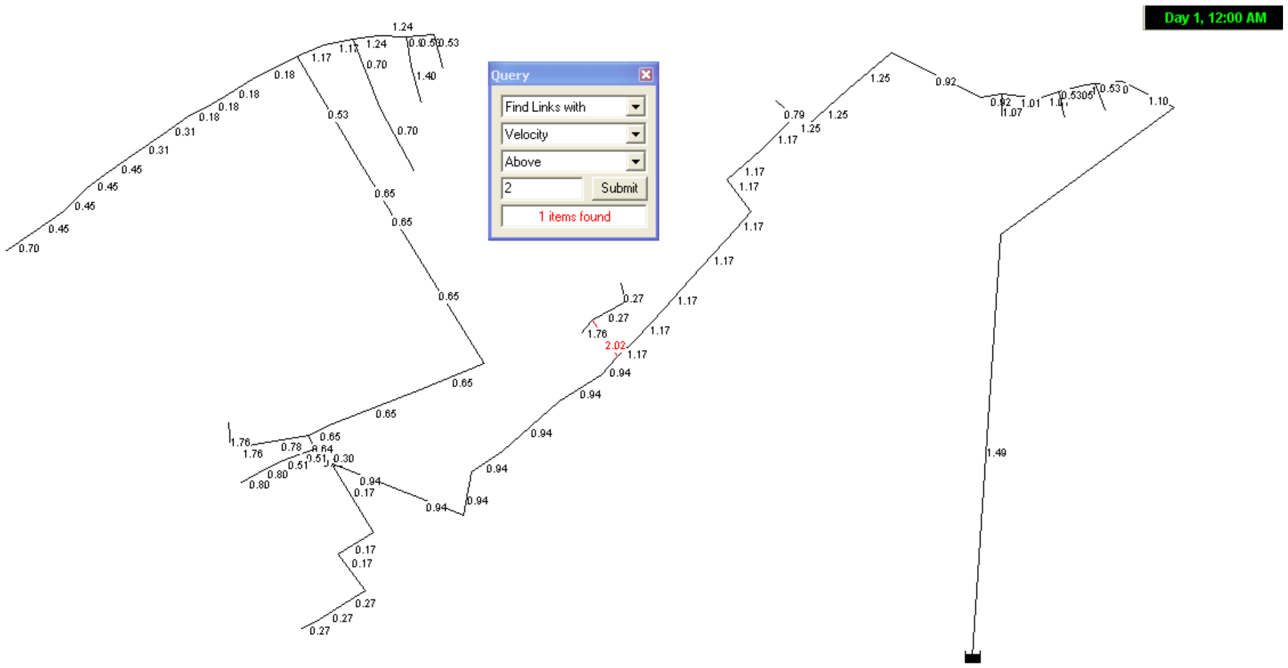


Figure D-19 Diversion JJ1 Demand Based on 25% flow – Option 3 – Velocity above 2m/s

D3: Diversion JJ2

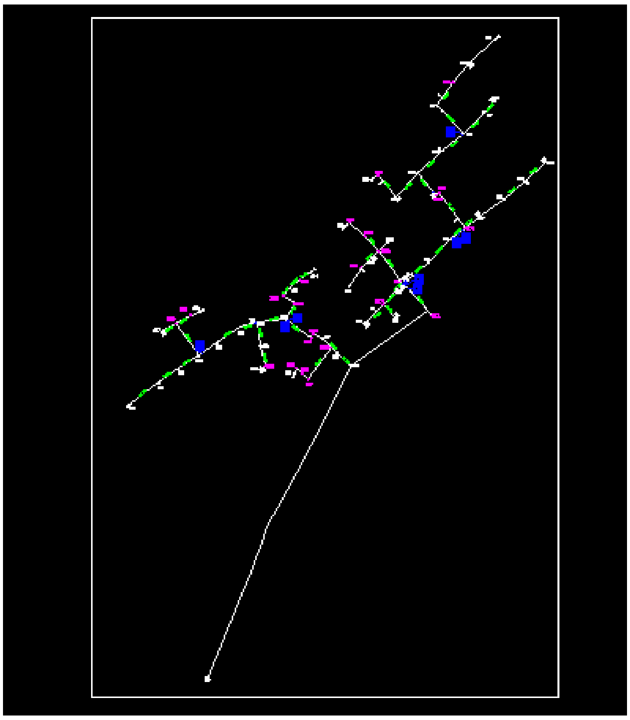


Figure D-20 Diversion JJ2

Table 3 Diversion JJ2 Flow Repartition

JJ-Diversion										
JJ2										
Node	Demand	75%			50%			25%		
		O1	O2	O3	O1	O2	O3	O1	O2	O3
510	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4		8.4
511	8.4	8.4	8.4		8.4	8.4				
512	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4		8.4
513	6.3	6.3	6.3	6.3	6.3	6.3				
514	6.3	6.3	6.3		6.3			6.3		
515	11	11	11	11	11		11			
516	11	11	11	11	11			11		
517	11	11	11	11	11		11			
518	8.4	8.4	8.4	8.4			8.4	8.4		
519	9.7	9.7	9.7		9.7					
520	11	11	11	11	11		11	11		11
521	8.4	8.4		8.4						
522	8.4	8.4		8.4	8.4		8.4	8.4		
523	8.4	8.4			8.4					
524	9.7	9.7		9.7	9.7		9.7	9.7		9.7
101	5.5	5.5		5.5	5.5		5.5			5.5
102	4.2	4.2		4.2						
103	4.2	4.2		4.2	4.2		4.2	4.2		4.2
106	9.7	9.7		9.7	9.7			9.7		
107	11	11			11					
108	5.5	5.5		5.5	5.5		5.5	5.5		5.5
621	4.2	4.2	4.2	4.2	4.2		4.2	4.2		4.2
622	6.3	6.3	6.3							
623	7.6	7.6	7.6	7.6	7.6		7.6	7.6		7.6
624	2.1	2.1	2.1	2.1	2.1		2.1	2.1		2.1
924	6.3		6.3	6.3		6.3	6.3		6.3	6.3
601	9.7		9.7	9.7		9.7				
602	8.4		8.4	8.4		8.4			8.4	
603	8.4		8.4			8.4			8.4	
604	8.4		8.4	8.4		8.4			8.4	
605	8.4		8.4			8.4			8.4	
606	8.4		8.4	8.4		8.4	8.4		8.4	8.4
607	9.7		9.7	9.7		9.7	9.7		9.7	9.7
608	4.2		4.2	4.2		4.2	4.2		4.2	4.2
609	2.1	2.1	2.1	2.1		2.1	2.1		2.1	2.1
610	6.3		6.3	6.3		6.3				
611	6.3		6.3	6.3		6.3	6.3		6.3	
612	9.7	9.7	9.7	9.7		9.7			9.7	

JJ-Diversion										
JJ2										
Node	**Demand**	**75%**			**50%**			**25%**		
		O1	**O2**	**O3**	**O1**	**O2**	**O3**	**O1**	**O2**	**O3**
613	9.7	9.7	9.7			9.7				
614	7.6	7.6	7.6	7.6		7.6	7.6		7.6	7.6
617	8.4	8.4	8.4	8.4		8.4	8.4		8.4	
618	8.4	8.4	8.4			8.4				
619	8.4	8.4	8.4	8.4		8.4	8.4		8.4	
Total	**333.9**	**249.4**	**258.9**	**248.9**	**167.8**	**170.3**	**166.8**	**104.9**	**104.7**	**104.9**
Percentage		**74.7**	**77.5**	**74.5**	**50.3**	**51.0**	**50.0**	**31.4**	**31.4**	**31.4**

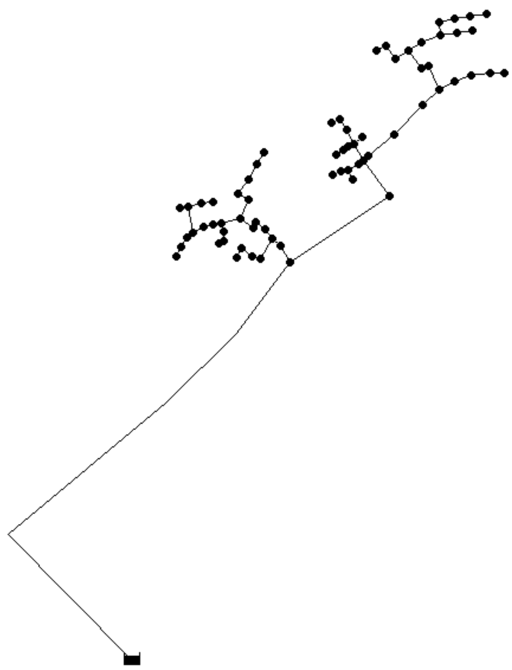


Figure D-21 Diversion JJ2 EpaNet Model

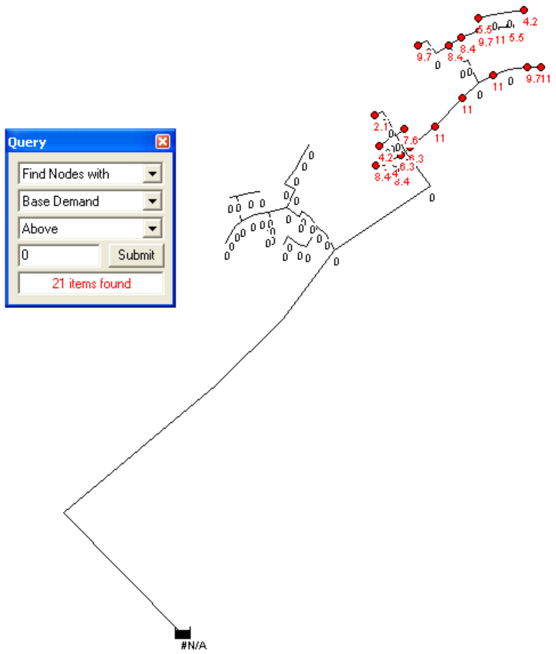


Figure D-22 Diversion JJ2 Demand Based on 50% Flow – Option 1

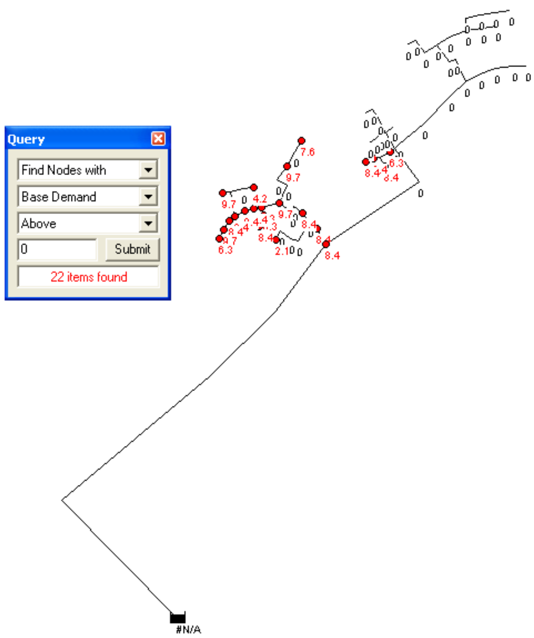


Figure D-23 Diversion JJ2 Demand Based on 50% Flow – Option 2

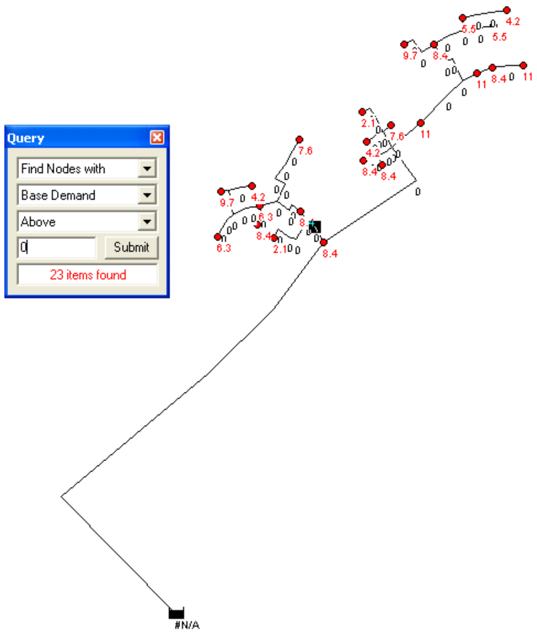


Figure D-24 Diversion JJ2 Demand Based on 50% Flow – Option 3

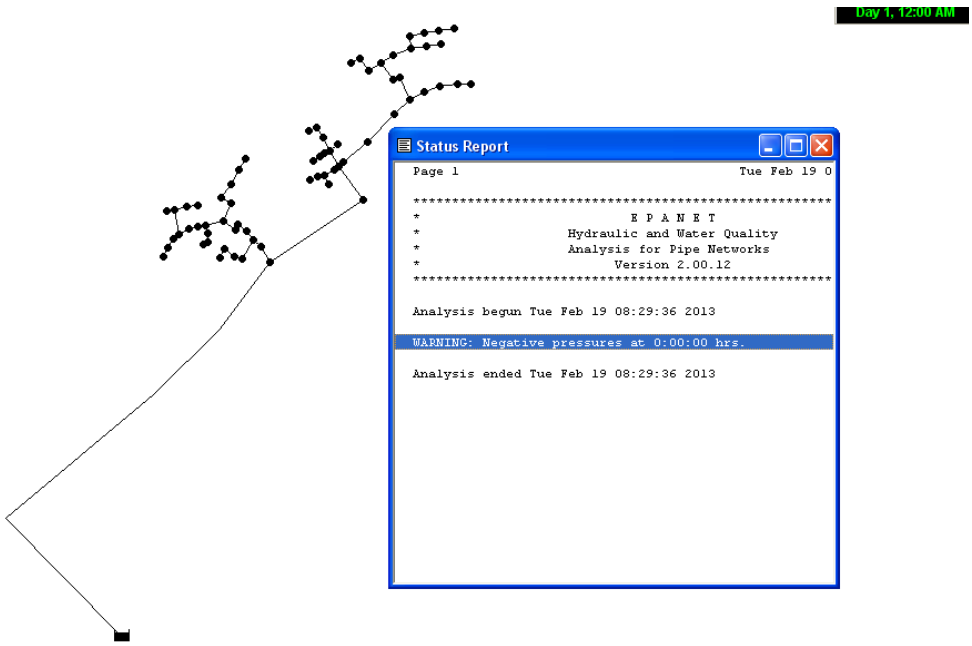


Figure D-25 Diversion JJ2 unsuccessful Simulation Report Based on 50% Flow Demand

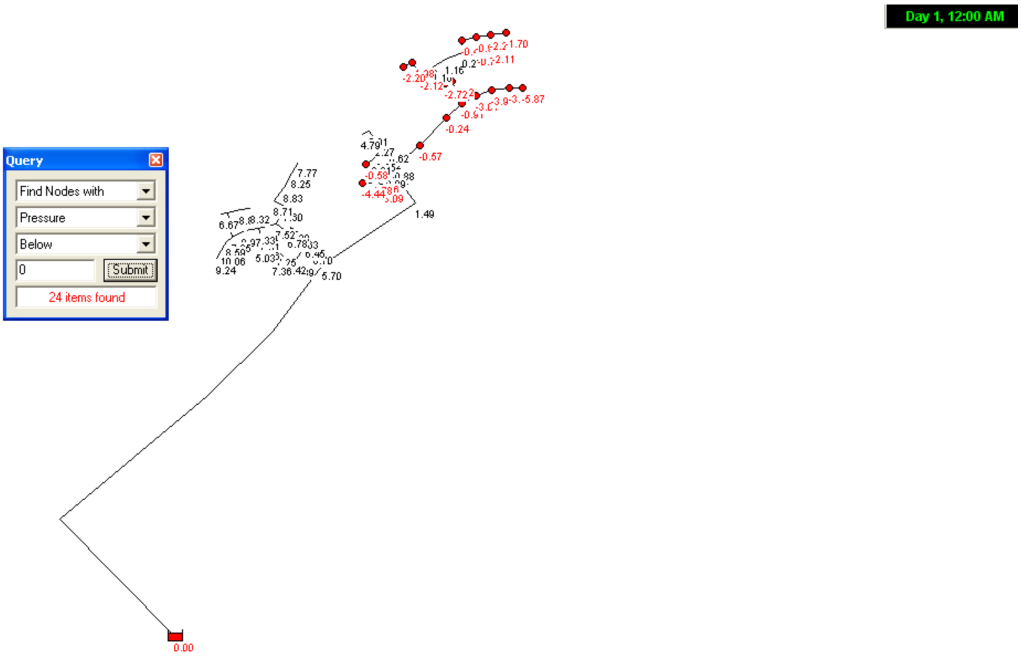


Figure D-26 Diversion JJ2 Demand Based on 50% Flow – Nodes with Negative Pressure

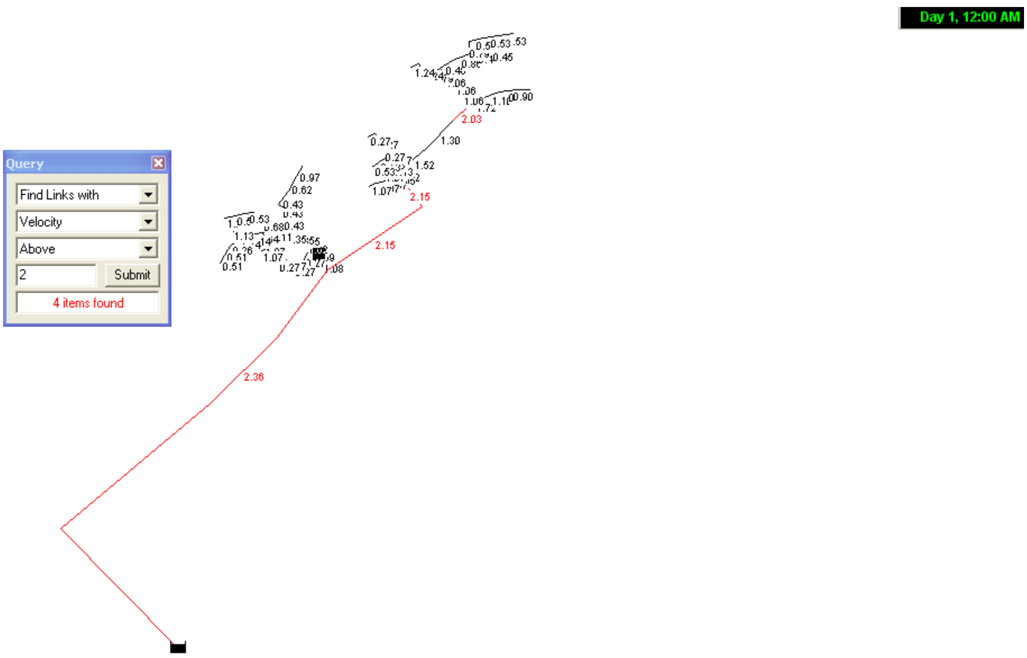


Figure D-27 Diversion JJ2 Demand Based on 50% Flow – Pipes with Velocity above 2m/s

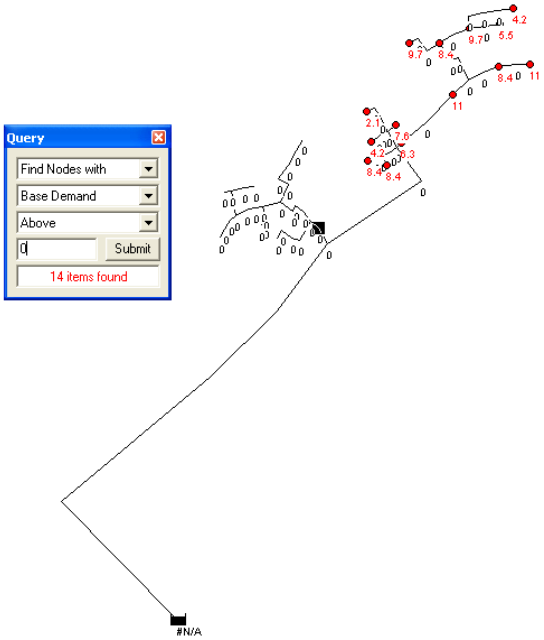


Figure D-28 Diversion JJ2 Demand Based on 25% flow – Option 1

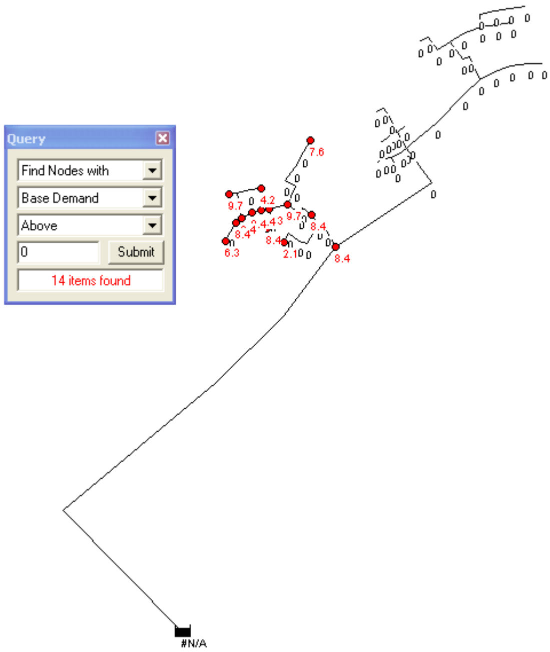


Figure D-29 Diversion JJ2 Demand Based on 25% flow – Option 2

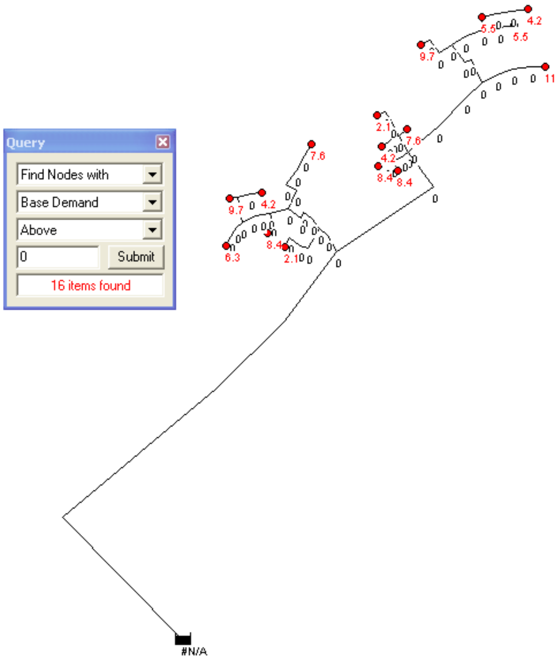


Figure D-30 Diversion JJ2 Demand Based on 25% flow – Option 3

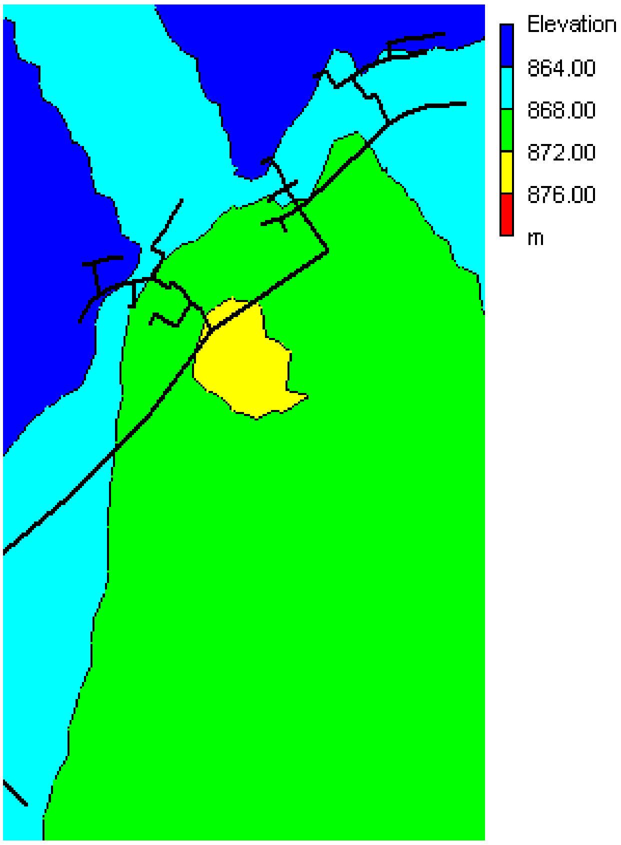


Figure D-31 Diversion JJ2 – Static Pressure Graph

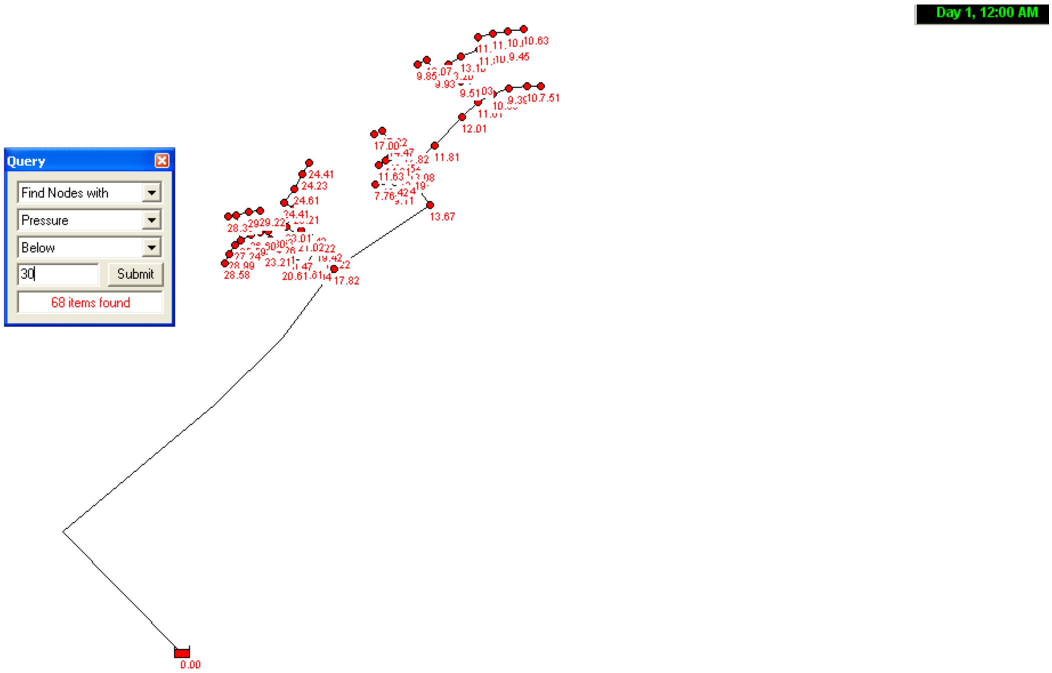


Figure D-32 Diversion JJ2 Demand Based on 25% flow – Option 1 – Pressure below 30m

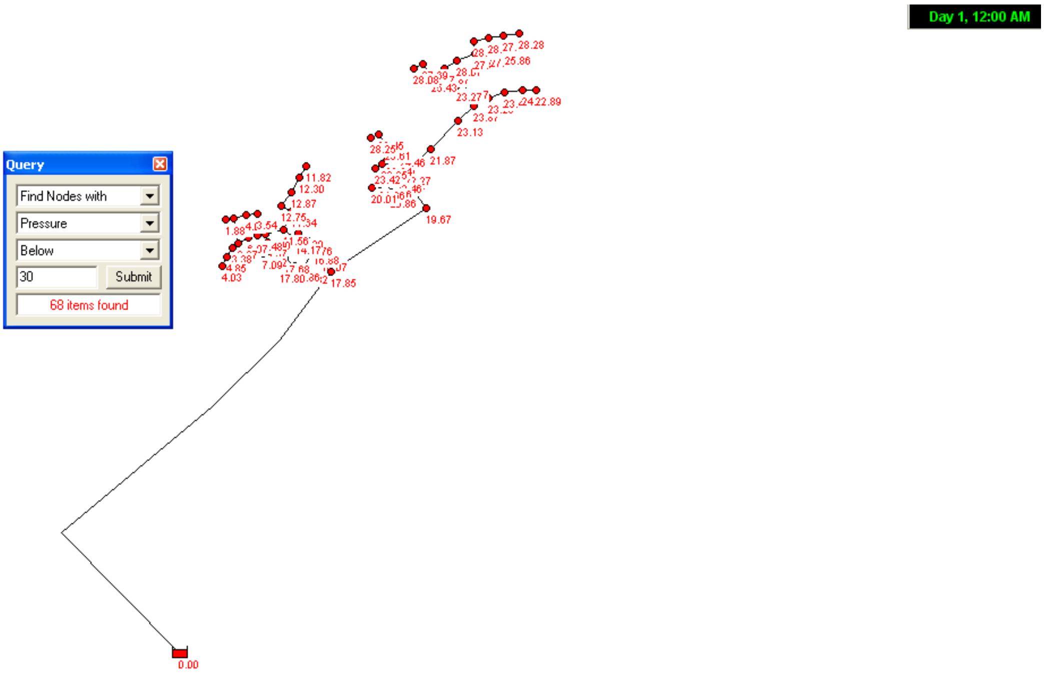


Figure D-33 Diversion JJ2 Demand Based on 25% flow – Option 2 – Pressure below 30m

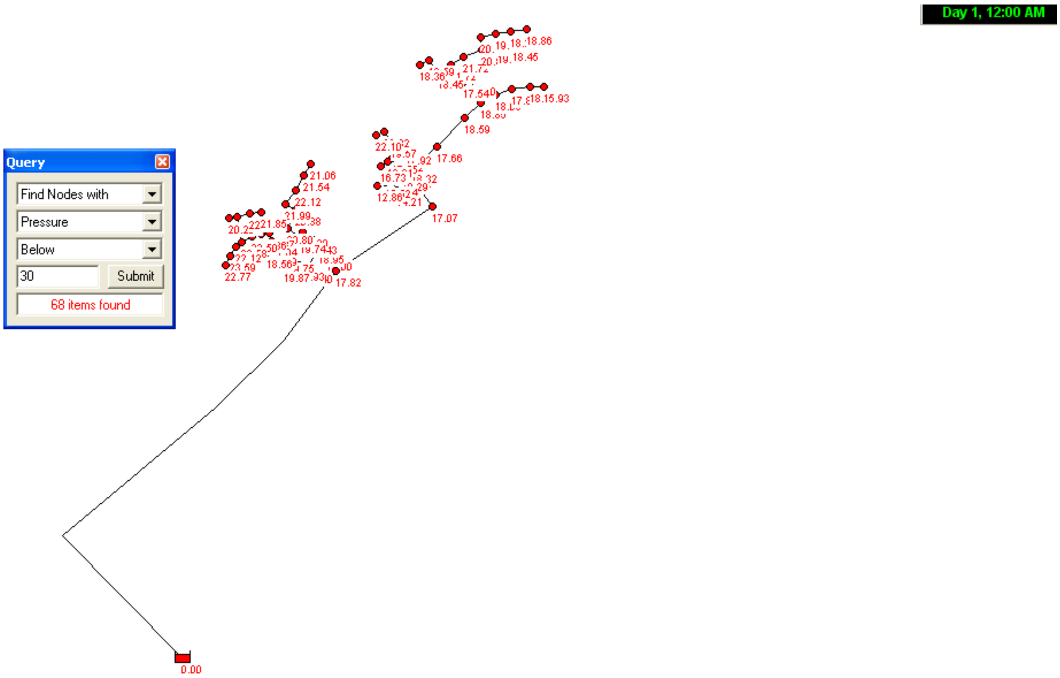


Figure D-34 Diversion JJ2 Demand Based on 25% flow – Option 3 – Pressure below 30m

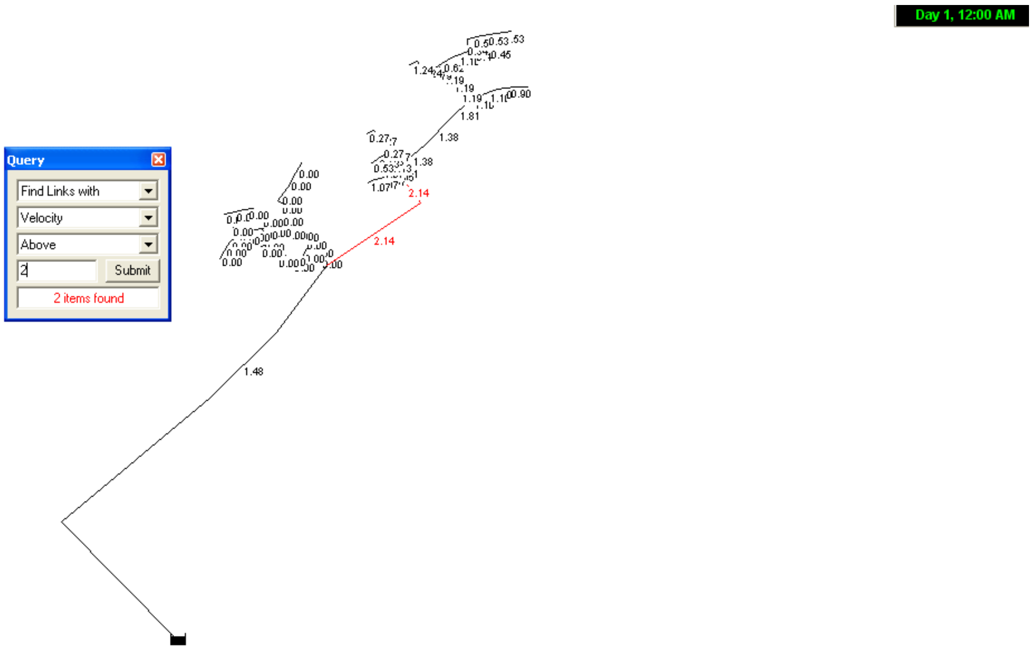


Figure D-35 Diversion JJ2 Demand Based on 25% flow – Option 1 – Velocity above 2m/s

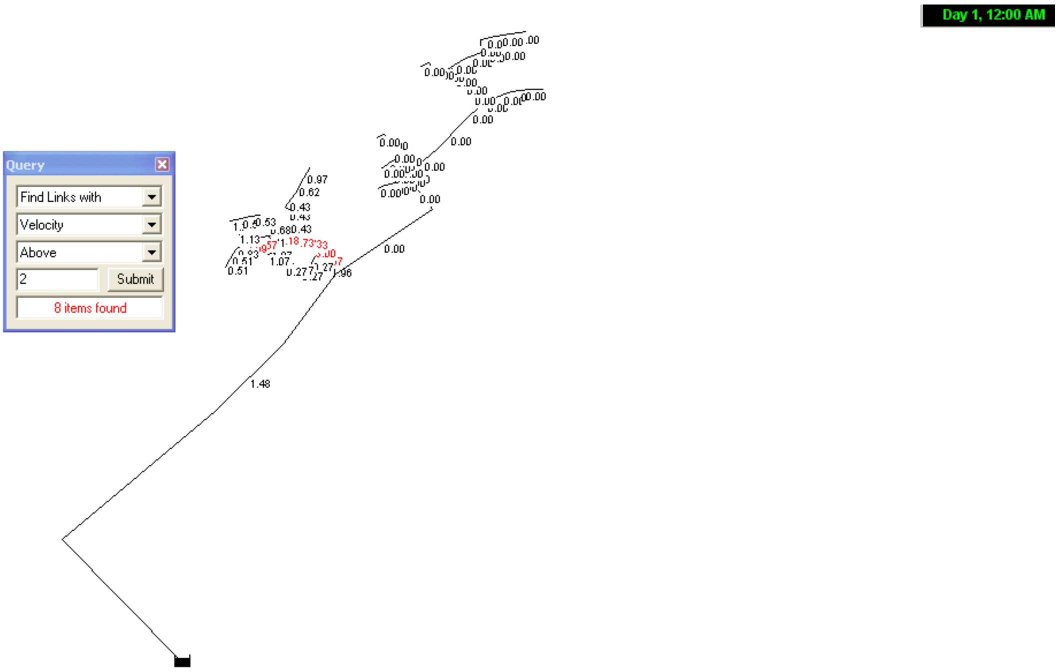


Figure D-36 Diversion JJ2 Demand Based on 25% flow – Option 2 – Velocity above 2m/s

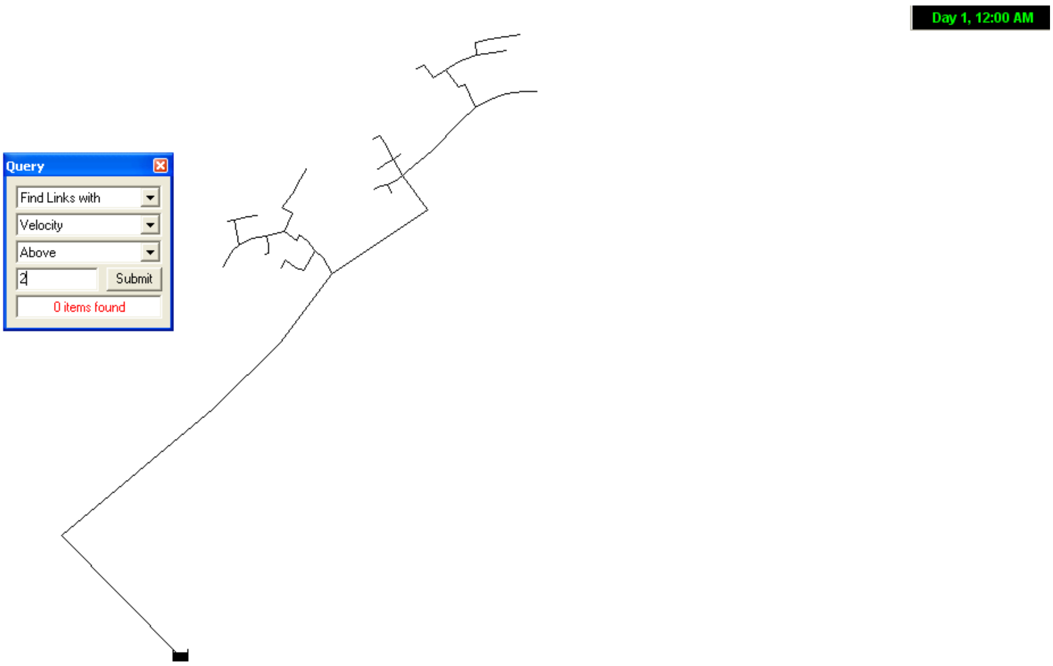


Figure D-37 Diversion JJ2 Demand Based on 25% flow – Option 3 – Velocity above 2m/s

APPENDIX E Simulations of K2 diversion for the 15m and 20m maximum pressure constraints

E.1: K2 – 15m

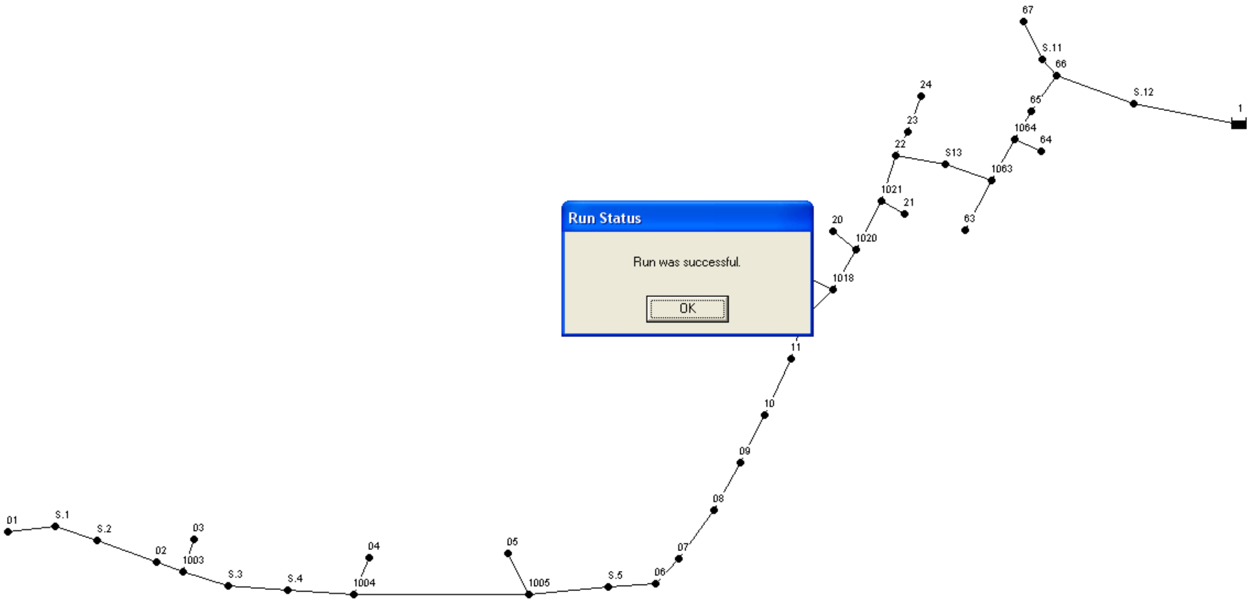


Figure E-1 K2 – 15m Successful Rum

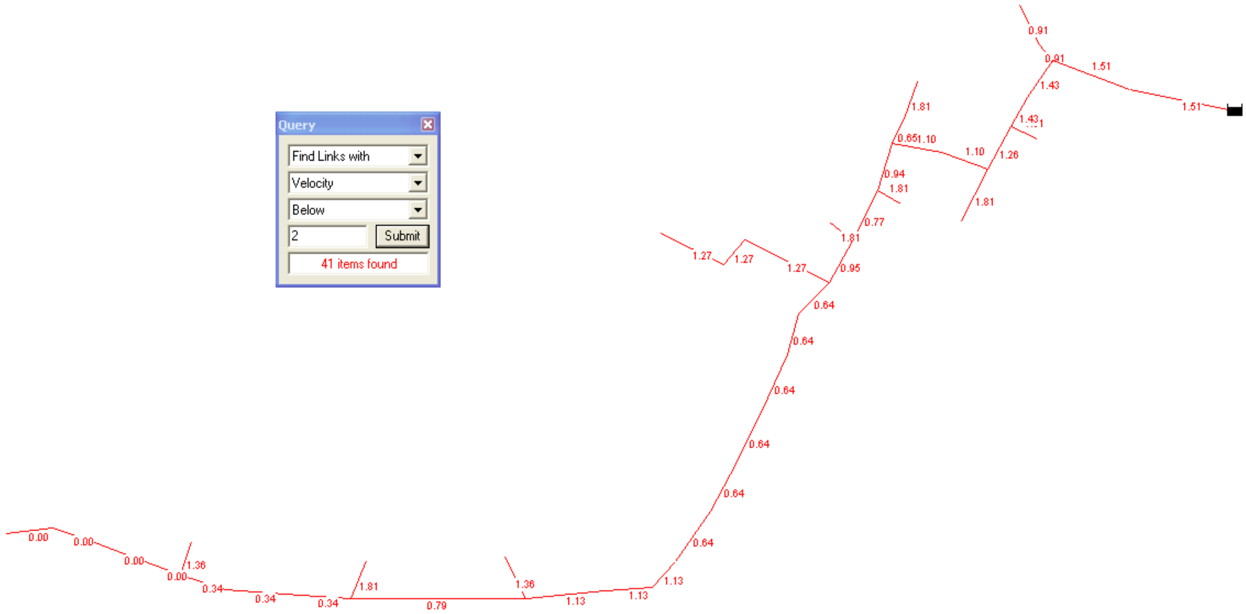


Figure E-2 K2 - 15m Pipes with velocity bellow 2m/s

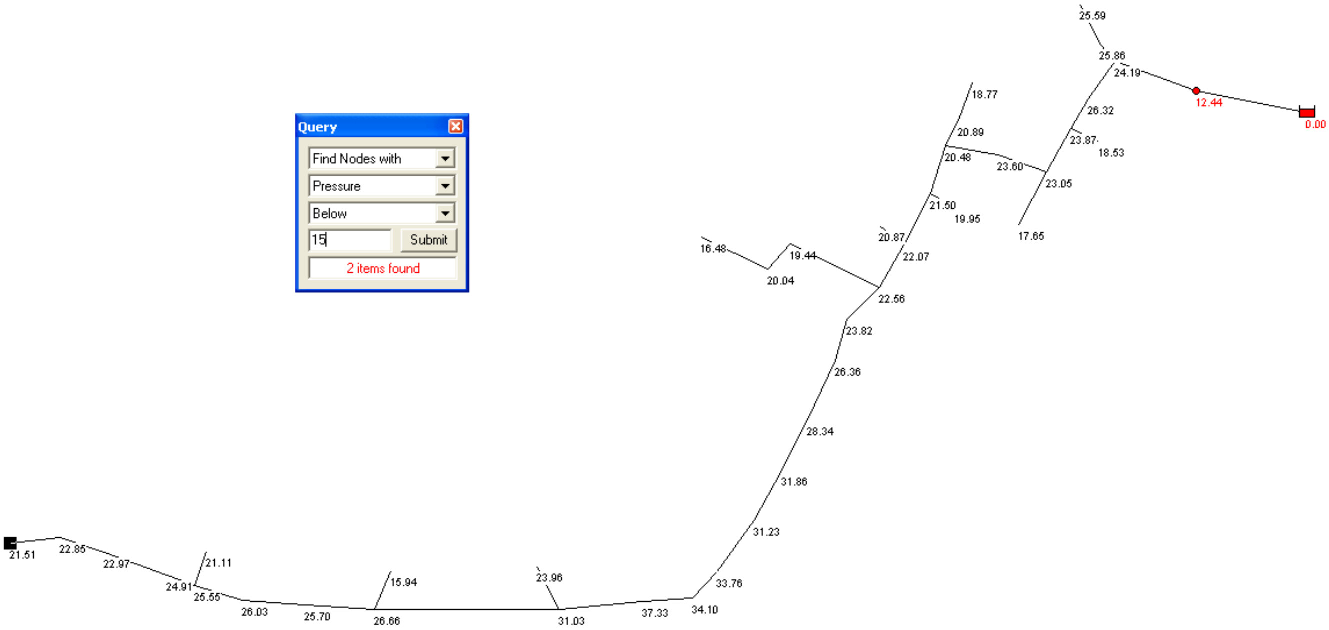


Figure E-3 K2 – 15m JJ2 – 20m Nodes with pressure below 15m

E2: K2-20m

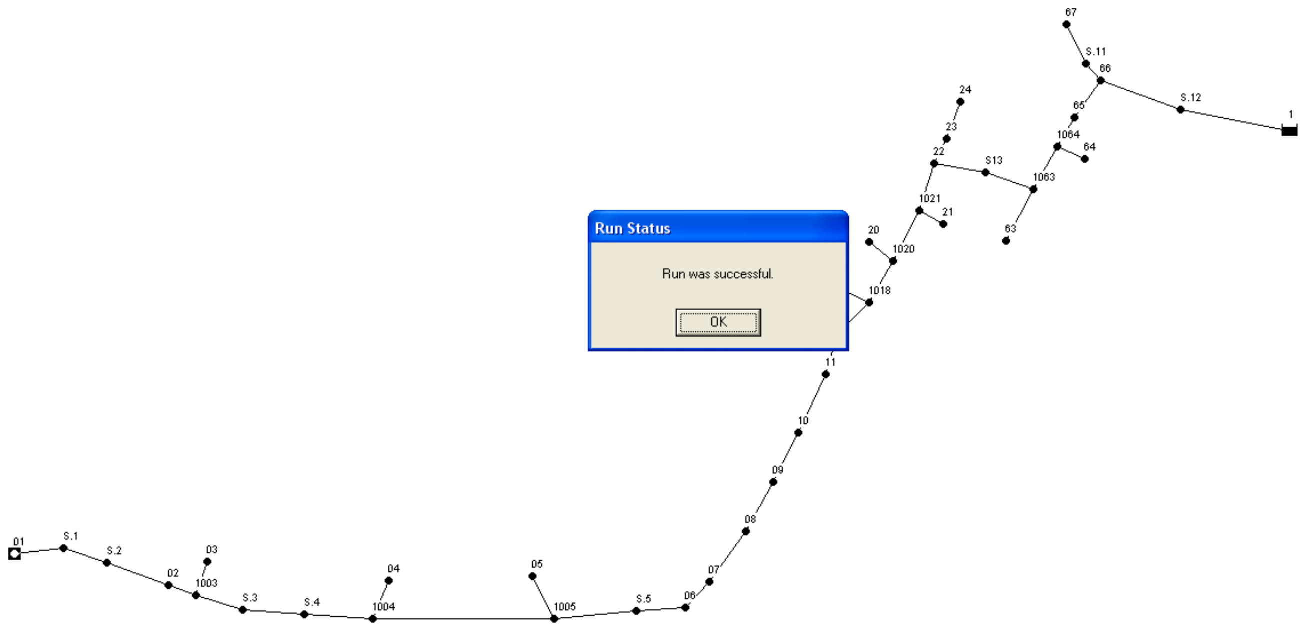


Figure E-4 K2 – 20m Successful Rum

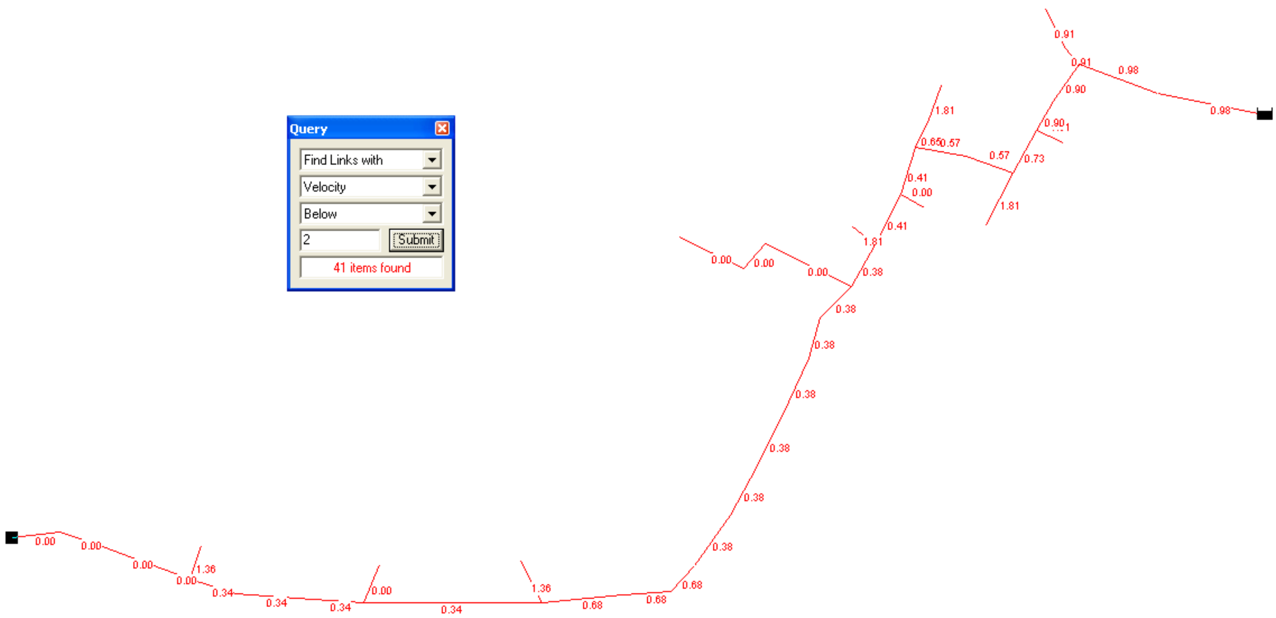


Figure E-5 K2 – 20m Pipes with velocity bellow 2m/s

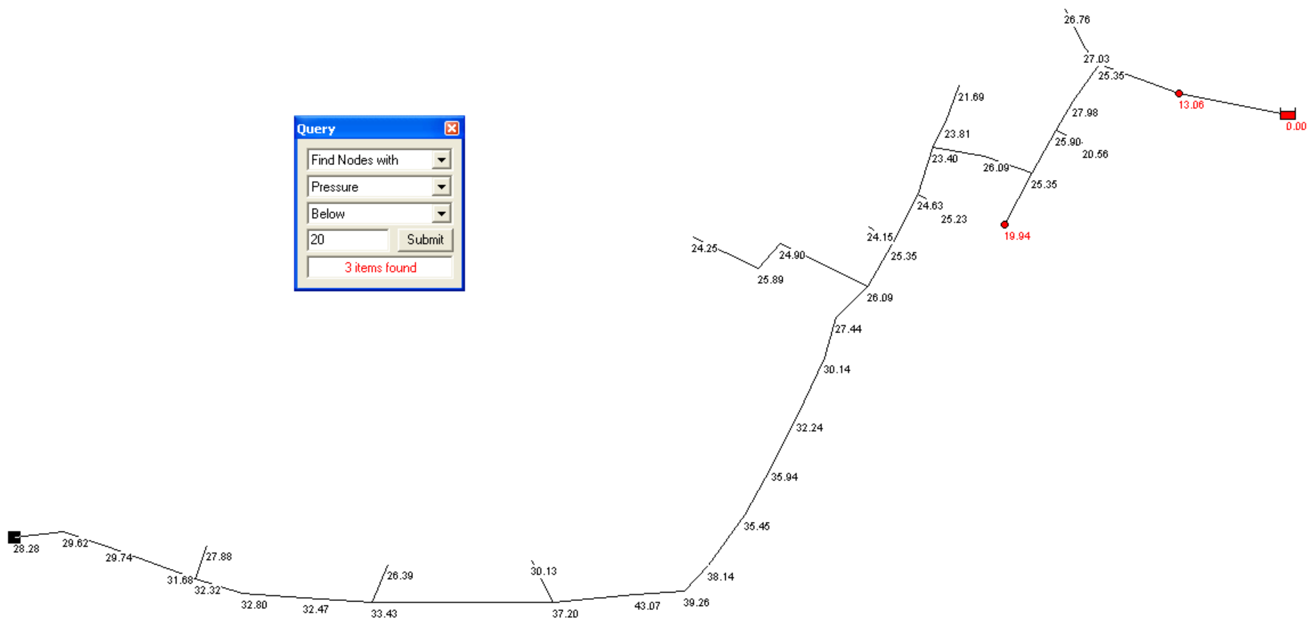


Figure E-6 K2 – 20m Nodes with pressure below 20m

APPENDIX F Simulations of Joub Jannine diversion for the 15m and 20m maximum pressure constraints

F.1: JJ1

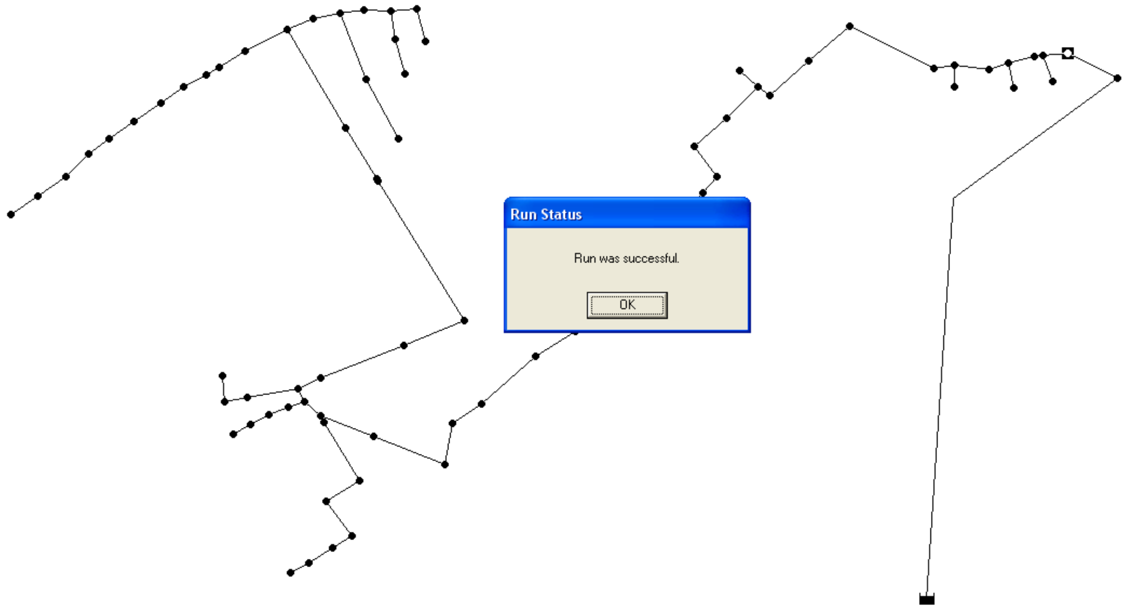


Figure F-1 JJ1 – 15m Successful Rum

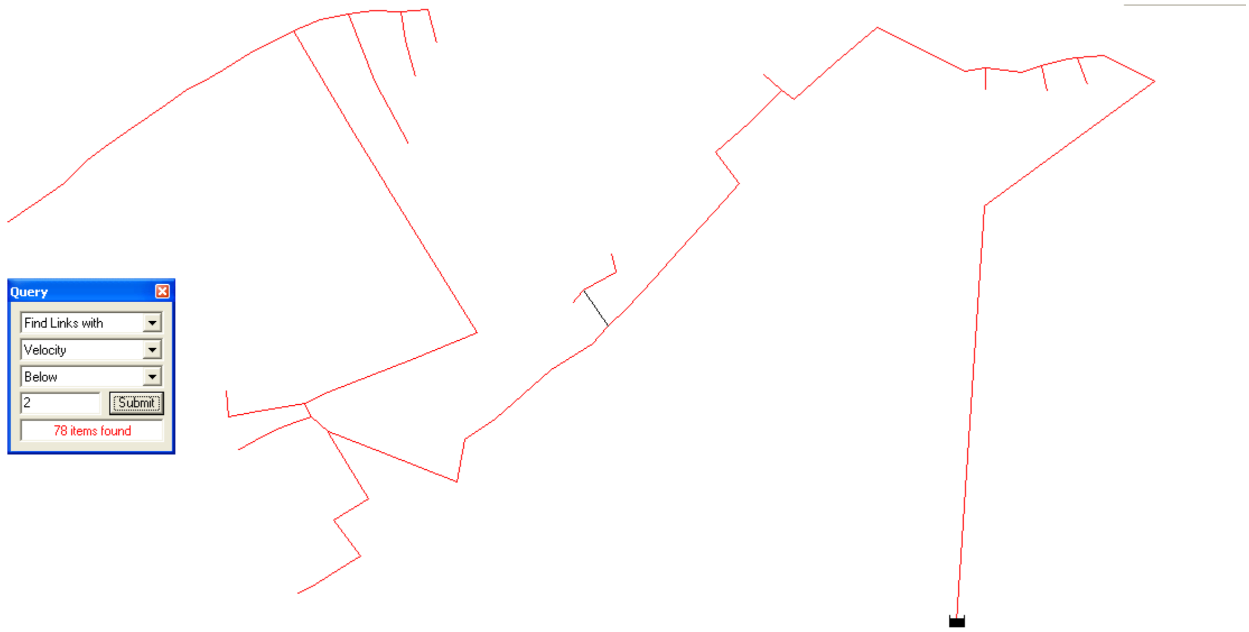


Figure F-2 JJ1 – 15m Pipes with velocity bellow 2m/s

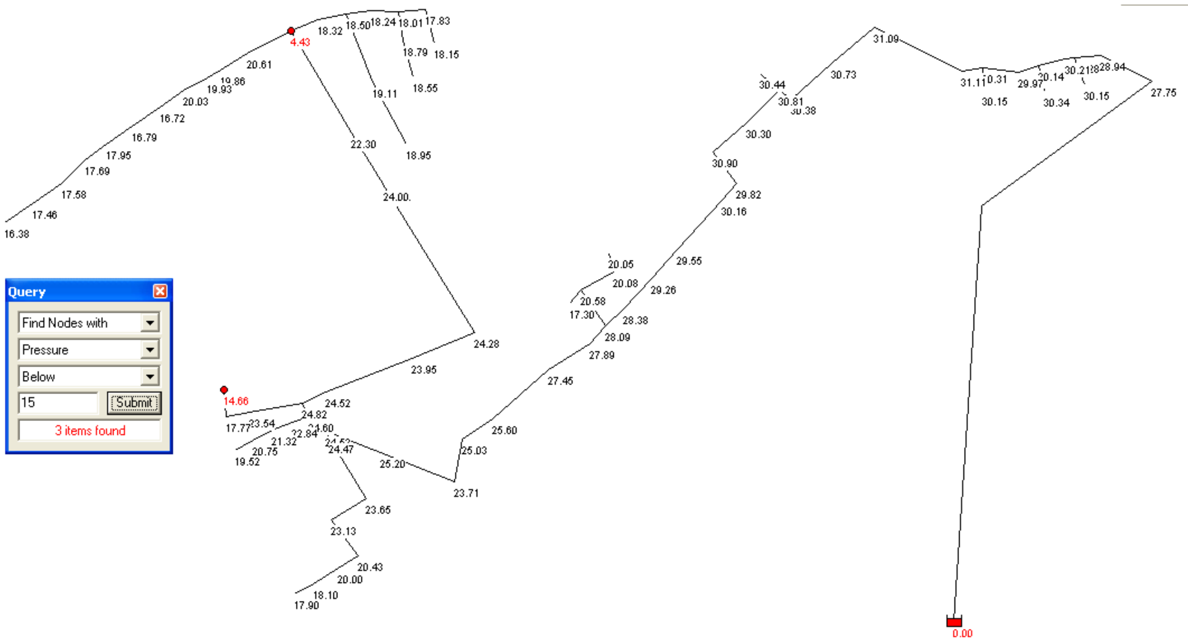


Figure F-3 JJ1 – 15m Nodes with pressure below 15m

F2: JJ1 – 20m

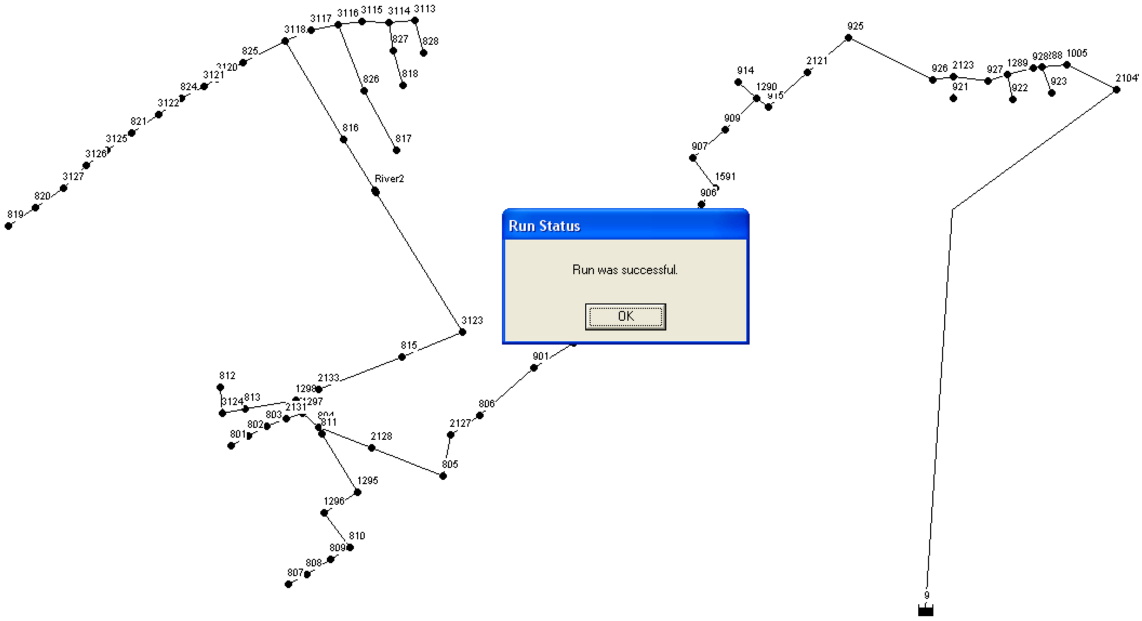


Figure F-4 JJ1 – 20m Successful Rum

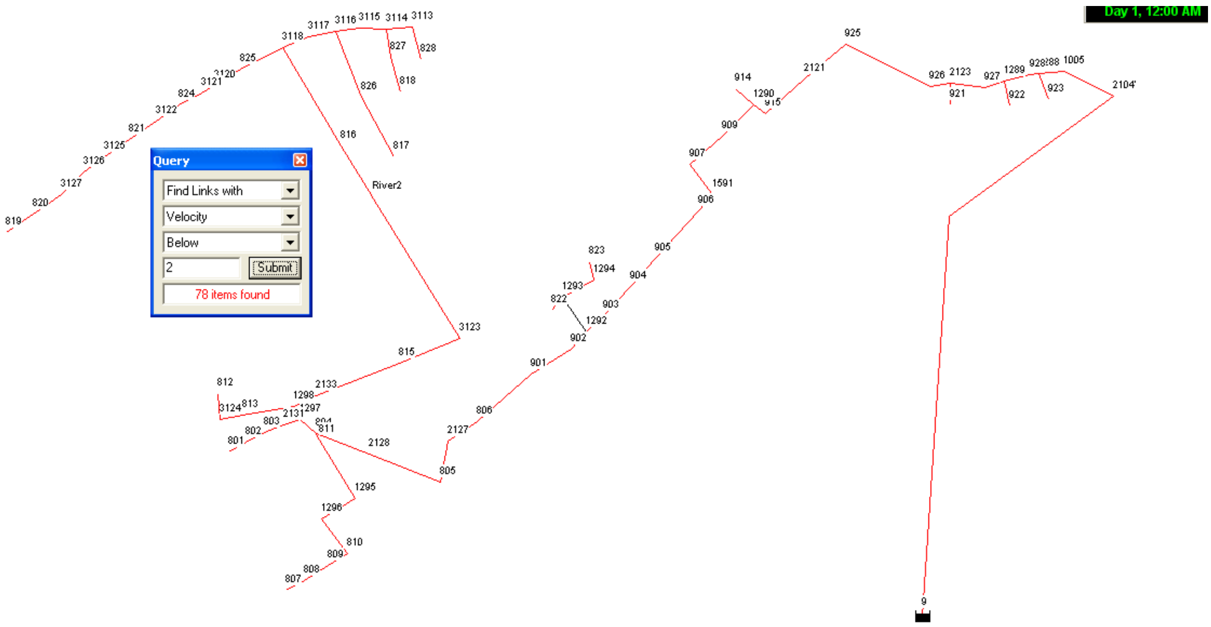


Figure F-5 JJ1 – 20m Pipes with velocity bellow 2m/s

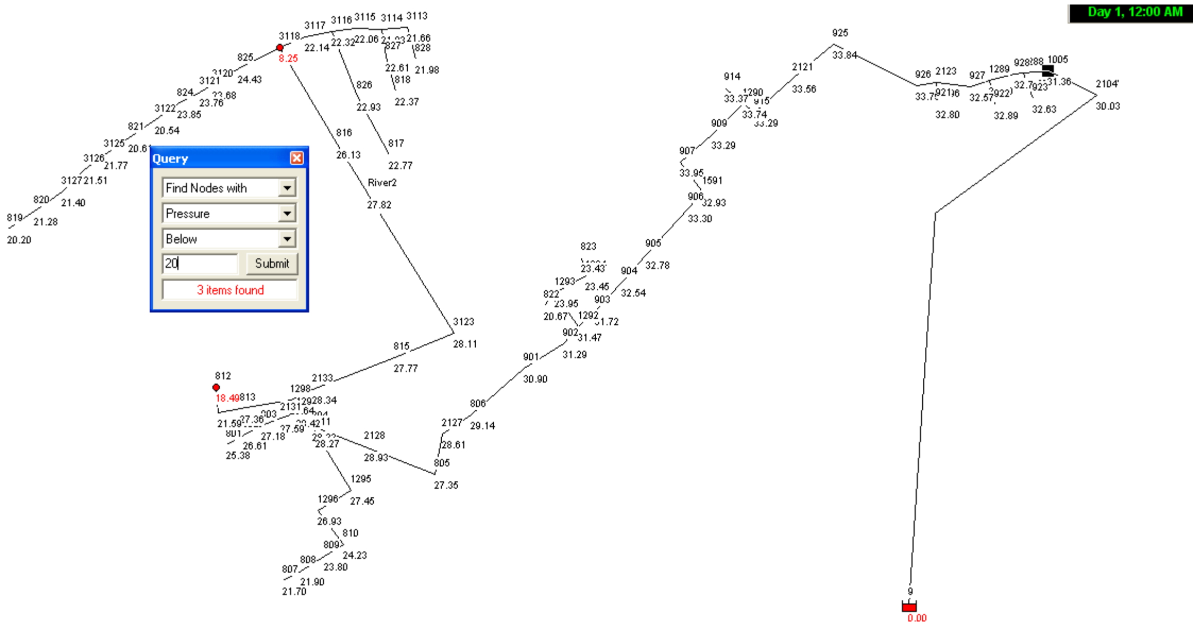


Figure F-6 **JJ1** – 20m Nodes with pressure below 20m

F3: JJ2 – 15m

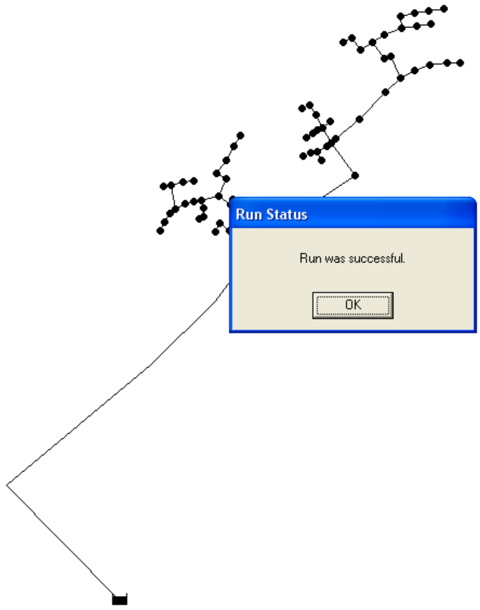


Figure F-7 JJ2 – 15m Successful Rum

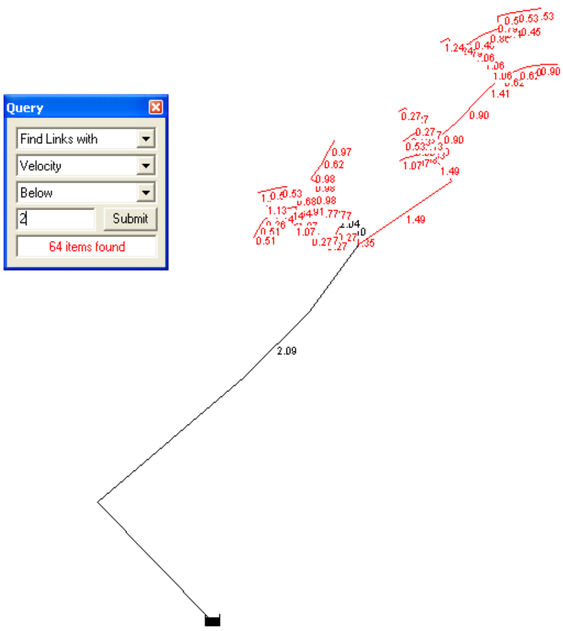


Figure F-8 JJ2 – 15m Pipes with velocity bellow 2m/s

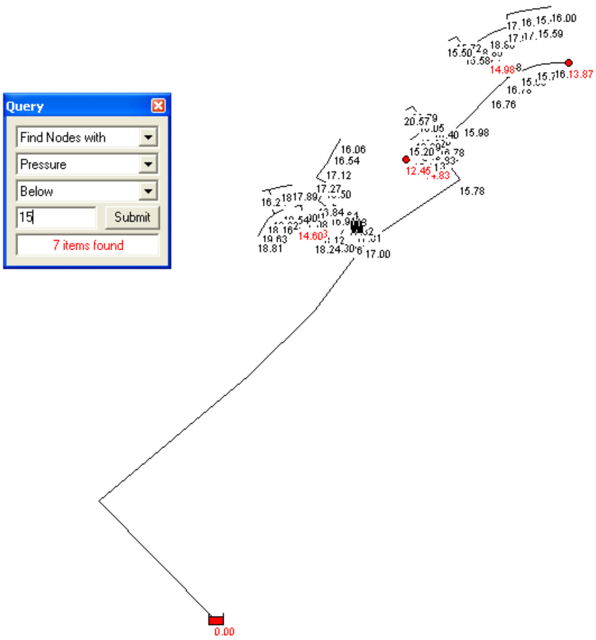


Figure F-9 JJ2 – 15m Nodes with pressure below 15m

F4: JJ2-20m

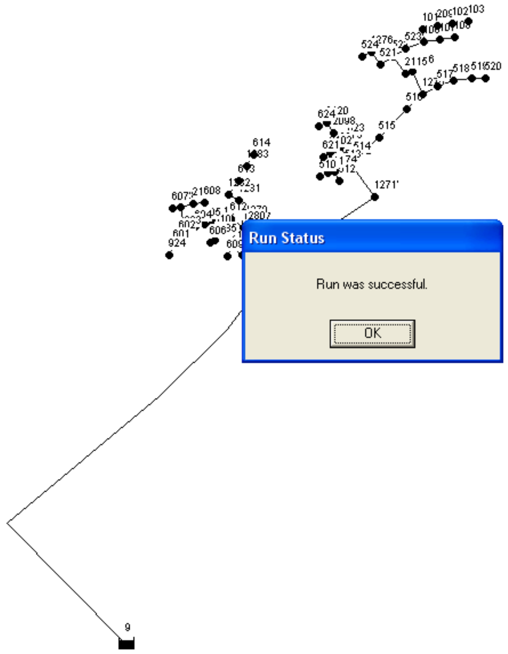


Figure F-10 JJ2 – 20m Successful Rum

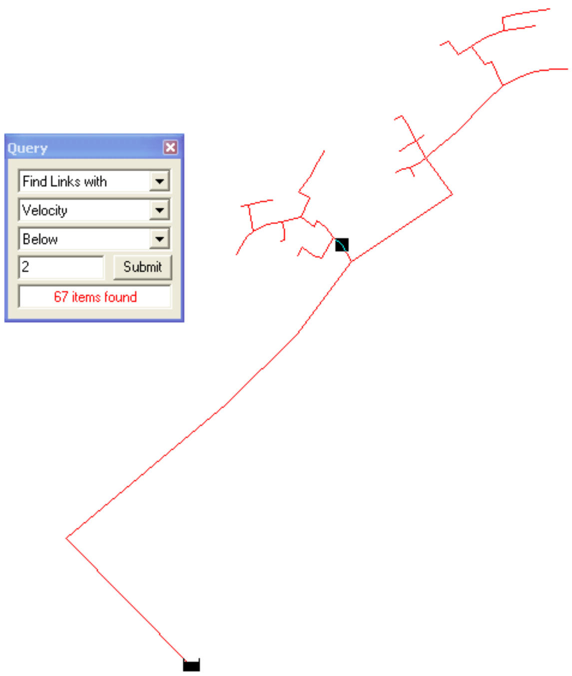


Figure F-11 **JJ2 –** 20m Pipes with velocity bellow 2m**/s**

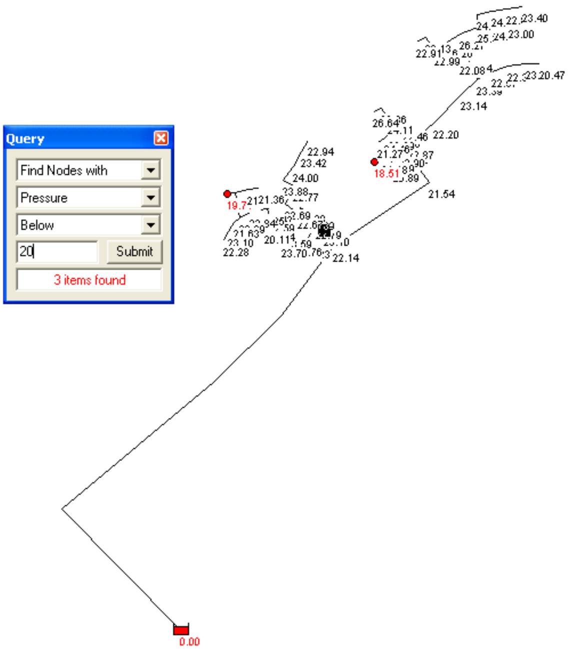


Figure F-12 JJ2 – 20m Nodes with pressure below 20m

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