DA2324_PRJ1_G184

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Chapter 1

Water Supply Management Analysis Tool

This project is a part of the Design of Algorithms course (DA) in Spring 2024.

1.1 Introduction

The Water Supply Management Analysis Tool is developed to assist the Management Team of a water supply network in Portugal in making informed decisions about resource allocation. The tool allows for the analysis of network metrics, evaluation of network resilience, and identification of potential improvements.

1.2 Problem Statement

The project aims to implement an analysis tool that supports the Management Team of a water supply network in making informed decisions about resource allocation, including financial and physical resources such as pumping stations and pipelines. The tool should allow management to allocate pumping stations to supply sources effectively, identify sensitive network sections, and mitigate service disruptions.

1.3 Running

To run the Water Supply Management Analysis Tool, please follow these steps:

```
mkdir build
cd build
cmake ..
make
./DA2324_PRJ1_G184
```

1.4 Usage

The tool provides the following functionalities:

- Calculation of maximum flow reaching each city in the network.
- Evaluation of water deficit or excess for each city.
- Analysis of the impact of reservoir, pumping station, and pipeline failures on network reliability.
- Balancing the load across the network to minimize flow differences.

1.4.0.1 Authors

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Chapter 2

Class Index

2.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 3

File Index

3.1 File List

Here is a list of all files with brief descriptions:

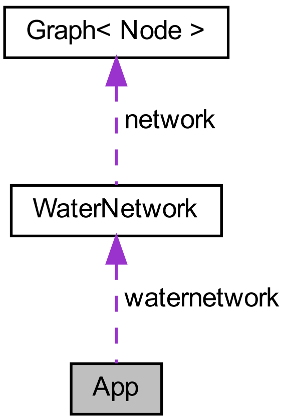
Chapter 4

Class Documentation

4.1 App Class Reference

`#include <App.hpp>`

Collaboration diagram for App:



Public Member Functions

- App (WaterNetwork &waternetwowk)
- std::string upperCase (const std::string &str)
- void mainMenu ()
- void goBackMainMenu ()
- void statisticsMenu ()
- void maxFlowMenu ()
- void waterNeedsMenu ()
- void reservoirImpactMenu ()
- void stationImpactMenu ()
- void pipeImpactMenu ()
- void balanceMenu ()

Private Attributes

- WaterNetwork waternetwork

4.1.1 Constructor & Destructor Documentation

4.1.1.1 App()

```
App::App (
            WaterNetwork & waternetwowk )
```

4.1.2 Member Function Documentation

4.1.2.1 balanceMenu()

```
void App::balanceMenu ( )
```

4.1.2.2 goBackMainMenu()

```
void App::goBackMainMenu ( )
```

4.1.2.3 mainMenu()

```
void App::mainMenu ( )
```

4.1.2.4 maxFlowMenu()

```
void App::maxFlowMenu ( )
```

4.1.2.5 pipeImpactMenu()

```
void App::pipeImpactMenu ( )
```

4.1.2.6 reservoirImpactMenu()

```
void App::reservoirImpactMenu ( )
```

4.1.2.7 stationImpactMenu()

```
void App::stationImpactMenu ( )
```

4.1.2.8 statisticsMenu()

```
void App::statisticsMenu ( )
```

4.1.2.9 upperCase()

```
std::string App::upperCase (
            const std::string & str )
```

4.1.2.10 waterNeedsMenu()

```
void App::waterNeedsMenu ( )
```

4.1.3 Member Data Documentation

4.1.3.1 waternetwork

```
WaterNetwork App::waternetwork [private]
```

The documentation for this class was generated from the following files:

- inc/App.hpp
- src/App.cpp

4.2 Edge< T > Class Template Reference

`#include <Graph.hpp>`

Public Member Functions

- Edge (Vertex< T > *orig, Vertex< T > *dest, double w)
- Vertex< T > * getDest () const
- double getWeight () const
- bool isSelected () const
- Vertex< T > * getOrig () const
- Edge< T > * getReverse () const
- double getFlow () const
- void setWeight (double weight)
- void setSelected (bool selected)
- void setReverse (Edge< T > *reverse)
- void setFlow (double flow)

Protected Attributes

- Vertex< T > * dest
- double weight
- bool selected = false
- Vertex< T > * orig
- Edge< T > * reverse = nullptr
- double flow

4.2.1 Constructor & Destructor Documentation

4.2.1.1 Edge()

```
template<class T >
Edge< T >::Edge (
            Vertex< T > * orig,
            Vertex< T > * dest,
            double w )
```

4.2.2 Member Function Documentation

4.2.2.1 getDest()

```
template<class T >
Vertex< T > * Edge< T >::getDest
```

4.2.2.2 getFlow()

```
template<class T >
double Edge< T >::getFlow
```

4.2.2.3 getOrig()

```
template<class T >
Vertex< T > * Edge< T >::getOrig
```

4.2.2.4 getReverse()

```
template<class T >
Edge< T > * Edge< T >::getReverse
```

4.2.2.5 getWeight()

```
template<class T >
double Edge< T >::getWeight
```

4.2.2.6 isSelected()

```
template<class T >
bool Edge< T >::isSelected
```

4.2.2.7 setFlow()

```
template<class T >
void Edge< T >::setFlow (
             double flow )
```

4.2.2.8 setReverse()

```
template<class T >
void Edge< T >::setReverse (
             Edge< T > * reverse )
```

4.2.2.9 setSelected()

```
template<class T >
void Edge< T >::setSelected (
            bool selected )
```

4.2.2.10 setWeight()

```
template<class T >
void Edge< T >::setWeight (
            double weight )
```

4.2.3 Member Data Documentation

4.2.3.1 dest

```
template<class T >
Vertex<T>* Edge< T >::dest [protected]
```

4.2.3.2 flow

```
template<class T >
double Edge< T >::flow [protected]
```

4.2.3.3 orig

```
template<class T >
Vertex<T>* Edge< T >::orig [protected]
```

4.2.3.4 reverse

```
template<class T >
Edge<T>* Edge< T >::reverse = nullptr [protected]
```

4.2.3.5 selected

```
template<class T >
bool Edge< T >::selected = false [protected]
```

4.2.3.6 weight

```
template<class T >
double Edge< T >::weight [protected]
```

The documentation for this class was generated from the following file:

- inc/Graph.hpp

4.3 Graph< T > Class Template Reference

```
#include <Graph.hpp>
```

Public Member Functions

- Vertex< T > * findVertex (const T &in) const
- bool addVertex (const T &in)
- bool removeVertex (const T &in)
- bool addEdge (const T &sourc, const T &dest, double w)
- bool removeEdge (const T &source, const T &dest)
- bool addBidirectionalEdge (const T &sourc, const T &dest, double w)
- int getNumVertex () const
- std::vector< Vertex< T > * > getVertexSet () const
- std::vector< T > dfs () const
- std::vector< T > dfs (const T &source) const
- void dfsVisit (Vertex< T > *v, std::vector< Vertex< T > * > &res) const
- std::vector< T > bfs (const T &source) const
- bool isDAG () const
- bool dfsIsDAG (Vertex< T > *v) const
- std::vector< T > topsort () const

Protected Member Functions

- int findVertexIdx (const T &in) const

Protected Attributes

- std::vector< Vertex< T > * > vertexSet

4.3.1 Member Function Documentation

4.3.1.1 addBidirectionalEdge()

```
template<class T >
bool Graph< T >::addBidirectionalEdge (
            const T & sourc,
            const T & dest,
            double w )
```

4.3.1.2 addEdge()

```
template<class T >
bool Graph< T >::addEdge (
            const T & sourc,
            const T & dest,
            double w )
```

4.3.1.3 addVertex()

```
template<class T >
bool Graph< T >::addVertex (
            const T & in )
```

4.3.1.4 bfs()

```
template<class T >
std::vector< T > Graph< T >::bfs (
            const T & source ) const
```

4.3.1.5 dfs() [1/2]

```
template<class T >
std::vector< T > Graph< T >::dfs
```

4.3.1.6 dfs() [2/2]

```
template<class T >
std::vector< T > Graph< T >::dfs (
            const T & source ) const
```

4.3.1.7 dfsIsDAG()

```
template<class T >
bool Graph< T >::dfsIsDAG (
            Vertex< T > * v ) const
```

Auxiliary function that visits a vertex (v) and its adjacent, recursively. Returns false (not acyclic) if an edge to a vertex in the stack is found.

4.3.1.8 dfsVisit()

```
template<class T >
void Graph< T >::dfsVisit (
            Vertex< T > * v,
            std::vector< Vertex< T > * > & res ) const
```

4.3.1.9 findVertex()

```
template<class T >
Vertex< T > * Graph< T >::findVertex (
            const T & in ) const
```

4.3.1.10 findVertexIdx()

```
template<class T >
int Graph< T >::findVertexIdx (
            const T & in ) const [protected]
```

4.3.1.11 getNumVertex()

```
template<class T >
int Graph< T >::getNumVertex
```

4.3.1.12 getVertexSet()

```
template<class T >
std::vector< Vertex< T > * > Graph< T >::getVertexSet
```

4.3.1.13 isDAG()

```
template<class T >
bool Graph< T >::isDAG
```

4.3.1.14 removeEdge()

```
template<class T >
bool Graph< T >::removeEdge (
            const T & source,
            const T & dest )
```

4.3.1.15 removeVertex()

```
template<class T >
bool Graph< T >::removeVertex (
            const T & in )
```

4.3.1.16 topsort()

```
template<class T >
std::vector< T > Graph< T >::topsort
```

4.3.2 Member Data Documentation

4.3.2.1 vertexSet

```
template<class T >
std::vector<Vertex<T> *> Graph< T >::vertexSet  [protected]
```

The documentation for this class was generated from the following file:

- inc/Graph.hpp

4.4 Node Class Reference

Represents a node in a network.

```
#include <Node.hpp>
```

Public Member Functions

- Node ()

  Default constructor.
- Node (const unsigned char &type, const std::string &code, const std::string &reservoir, const std::string &municipality, const int &maxDelivery)

  Constructor for a reservoir node.
- Node (const unsigned char &type, const std::string &code)

  Constructor for a station node.
- Node (const unsigned char &type, const std::string &code, const std::string &municipality, const int &demand)

  Constructor for a city node.
- Node (const std::string &code)

  Constructor to find nodes.
- size_t getType () const

  Get the type of the node.
- std::string getCode () const

  Get the code associated with the node.
- std::string getReservoir () const

  Get the name of the reservoir.
- std::string getMunicipality () const

  Get the name of the municipality.
- int getMaxDelivery () const

  Get the maximum delivery of the reservoir.
- int getDemand () const

  Get the demand of the city.
- int getPopulation () const

  Get the population of the city.
- bool operator== (const Node &other)

  Overloaded equality operator.

Private Attributes

- unsigned char type
- std::string code
- std::string reservoir
- std::string municipality
- int maxDelivery
- int demand
- int population

4.4.1 Detailed Description

Represents a node in a network.

4.4.2 Constructor & Destructor Documentation

4.4.2.1 Node() [1/5]

```
Node::Node ( )
```

Default constructor.

4.4.2.2 Node() [2/5]

```
Node::Node (
            const unsigned char & type,
            const std::string & code,
            const std::string & reservoir,
            const std::string & municipality,
            const int & maxDelivery )
```

Constructor for a reservoir node.

Parameters

type	The type of the node.
code	The code associated with the node.
reservoir	The name of the reservoir.
municipality	The name of the municipality.
maxDelivery	The maximum delivery of the reservoir.

4.4.2.3 Node() [3/5]

```
Node::Node (
            const unsigned char & type,
            const std::string & code )
```

Constructor for a station node.

Parameters

type	The type of the node.
code	The code associated with the node.

4.4.2.4 Node() [4/5]

```
Node::Node (
            const unsigned char & type,
            const std::string & code,
            const std::string & municipality,
            const int & demand )
```

Constructor for a city node.

Parameters

type	The type of the node.
code	The code associated with the node.
municipality	The name of the municipality.
demand	The demand of the city.

4.4.2.5 Node() [5/5]

```
Node::Node (
            const std::string & code )
```

Constructor to find nodes.

Parameters

code	The code associated with the node.

4.4.3 Member Function Documentation

4.4.3.1 getCode()

```
std::string Node::getCode ( ) const
```

Get the code associated with the node.

Returns

The code associated with the node.

4.4.3.2 getDemand()

`int Node::getDemand ( ) const`

Get the demand of the city.

Returns

The demand of the city.

4.4.3.3 getMaxDelivery()

`int Node::getMaxDelivery ( ) const`

Get the maximum delivery of the reservoir.

Returns

The maximum delivery of the reservoir.

4.4.3.4 getMunicipality()

`std::string Node::getMunicipality ( ) const`

Get the name of the municipality.

Returns

The name of the municipality.

4.4.3.5 getPopulation()

`int Node::getPopulation ( ) const`

Get the population of the city.

Returns

The population of the city.

4.4.3.6 getReservoir()

```
std::string Node::getReservoir ( ) const
```

Get the name of the reservoir.

Returns

The name of the reservoir.

4.4.3.7 getType()

```
size_t Node::getType ( ) const
```

Get the type of the node.

Returns

The type of the node.

4.4.3.8 operator==()

```
bool Node::operator== (
            const Node & other )
```

Overloaded equality operator.

Parameters

other	The other node to compare.

Returns

True if the nodes codes are equal, false otherwise.

4.4.4 Member Data Documentation

4.4.4.1 code

```
std::string Node::code  [private]
```

4.4.4.2 demand

```
int Node::demand  [private]
```

4.4.4.3 maxDelivery

```
int Node::maxDelivery  [private]
```

4.4.4.4 municipality

```
std::string Node::municipality  [private]
```

4.4.4.5 population

```
int Node::population  [private]
```

4.4.4.6 reservoir

```
std::string Node::reservoir  [private]
```

4.4.4.7 type

```
unsigned char Node::type  [private]
```

The documentation for this class was generated from the following files:

- inc/Node.hpp
- src/Node.cpp

4.5 Vertex< T > Class Template Reference

```
#include <Graph.hpp>
```

Public Member Functions

- Vertex (T in)
- T getInfo () const
- std::vector< Edge< T > * > getAdj () const
- bool isVisited () const
- bool isProcessing () const
- unsigned int getIndegree () const
- double getDist () const
- Edge< T > * getPath () const
- std::vector< Edge< T > * > getIncoming () const
- double getCurrentFlow () const
- void setCurrentFlow (const double &cur)
- double getUsedDelivery () const
- void setUsedDelivery (const double &used)
- void setInfo (T info)
- void setVisited (bool visited)
- void setProcesssing (bool processing)
- void setIndegree (unsigned int indegree)
- void setDist (double dist)
- void setPath (Edge< T > *path)
- Edge< T > * addEdge (Vertex< T > *dest, double w)
- bool removeEdge (T in)
- void removeOutgoingEdges ()

Protected Member Functions

- void deleteEdge (Edge< T > *edge)

Protected Attributes

- T info
- std::vector< Edge< T > * > adj
- bool visited = false
- bool processing = false
- unsigned int indegree
- double dist = 0
- double currentFlow = 0
- double usedDelivery = 0
- Edge< T > * path = nullptr
- std::vector< Edge< T > * > incoming

4.5.1 Constructor & Destructor Documentation

4.5.1.1 Vertex()

```
template<class T >
Vertex< T >::Vertex (
            T in )
```

4.5.2 Member Function Documentation

4.5.2.1 addEdge()

```
template<class T >
Edge< T > * Vertex< T >::addEdge (
            Vertex< T > * dest,
            double w )
```

4.5.2.2 deleteEdge()

```
template<class T >
void Vertex< T >::deleteEdge (
            Edge< T > * edge )  [protected]
```

4.5.2.3 getAdj()

```
template<class T >
std::vector< Edge< T > * > Vertex< T >::getAdj
```

4.5.2.4 getCurrentFlow()

```
template<class T >
double Vertex< T >::getCurrentFlow
```

4.5.2.5 getDist()

```
template<class T >
double Vertex< T >::getDist
```

4.5.2.6 getIncoming()

```
template<class T >
std::vector< Edge< T > * > Vertex< T >::getIncoming
```

4.5.2.7 getIndegree()

```
template<class T >
unsigned int Vertex< T >::getIndegree
```

4.5.2.8 getInfo()

```
template<class T >
T Vertex< T >::getInfo
```

4.5.2.9 getPath()

```
template<class T >
Edge< T > * Vertex< T >::getPath
```

4.5.2.10 getUsedDelivery()

```
template<class T >
double Vertex< T >::getUsedDelivery
```

4.5.2.11 isProcessing()

```
template<class T >
bool Vertex< T >::isProcessing
```

4.5.2.12 isVisited()

```
template<class T >
bool Vertex< T >::isVisited
```

4.5.2.13 removeEdge()

```
template<class T >
bool Vertex< T >::removeEdge (
             T in )
```

4.5.2.14 removeOutgoingEdges()

```
template<class T >
void Vertex< T >::removeOutgoingEdges
```

4.5.2.15 setCurrentFlow()

```
template<class T >
void Vertex< T >::setCurrentFlow (
             const double & cur )
```

4.5.2.16 setDist()

```
template<class T >
void Vertex< T >::setDist (
             double dist )
```

4.5.2.17 setIndegree()

```
template<class T >
void Vertex< T >::setIndegree (
             unsigned int indegree )
```

4.5.2.18 setInfo()

```
template<class T >
void Vertex< T >::setInfo (
             T info )
```

4.5.2.19 setPath()

```
template<class T >
void Vertex< T >::setPath (
             Edge< T > * path )
```

4.5.2.20 setProcesssing()

```
template<class T >
void Vertex< T >::setProcesssing (
             bool processing )
```

4.5.2.21 setUsedDelivery()

```
template<class T >
void Vertex< T >::setUsedDelivery (
             const double & used )
```

4.5.2.22 setVisited()

```
template<class T >
void Vertex< T >::setVisited (
             bool visited )
```

4.5.3 Member Data Documentation

4.5.3.1 adj

```
template<class T >
std::vector<Edge<T> *> Vertex< T >::adj  [protected]
```

4.5.3.2 currentFlow

```
template<class T >
double Vertex< T >::currentFlow = 0  [protected]
```

4.5.3.3 dist

```
template<class T >
double Vertex< T >::dist = 0  [protected]
```

4.5.3.4 incoming

```
template<class T >
std::vector<Edge<T> *> Vertex< T >::incoming [protected]
```

4.5.3.5 indegree

```
template<class T >
unsigned int Vertex< T >::indegree [protected]
```

4.5.3.6 info

```
template<class T >
T Vertex< T >::info [protected]
```

4.5.3.7 path

```
template<class T >
Edge<T>* Vertex< T >::path = nullptr [protected]
```

4.5.3.8 processing

```
template<class T >
bool Vertex< T >::processing = false [protected]
```

4.5.3.9 usedDelivery

```
template<class T >
double Vertex< T >::usedDelivery = 0 [protected]
```

4.5.3.10 visited

```
template<class T >
bool Vertex< T >::visited = false [protected]
```

The documentation for this class was generated from the following file:

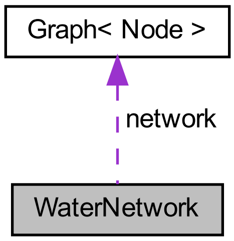
- inc/Graph.hpp

4.6 WaterNetwork Class Reference

Class representing a water supply network.

```
#include <WaterNetwork.hpp>
```

Collaboration diagram for WaterNetwork:



Public Member Functions

- WaterNetwork ()

  Default constructor for the WaterNetwork class.
- WaterNetwork (const std::string reservoirs_filename, const std::string stations_filename, const std::string cities_filename, const std::string pipes_filename)

  Constructor for the WaterNetwork class. This constructor initializes a water network graph by parsing data from provided files.
- ~WaterNetwork ()

  Destructor for the WaterNetwork class.
- Graph$<$ Node $>$ $*$ getNetworkGraph () const

  Getter for the network graph.
- double singleSinkMaxFlow (const std::string &city_code) const

  Determine the maximum amount of water that can reach a specific city. (T2.1)
- std::vector$<$ std::pair$<$ std::string, double $>$ $>$ multiSinkMaxFlow (Graph$<$ Node $>$ $*$g, const bool &flag) const

  Determine the maximum amount of water that can reach each city in the water supply network. (T2.1)
- std::vector$<$ std::pair$<$ std::string, double $>$ $>$ multiWaterNeeds (Graph$<$ Node $>$ $*$g, const bool &flag) const

  Determine the water deficit or excess for each city in the water supply network. (T2.2)
- std::vector$<$ std::pair$<$ std::string, double $>$ $>$ calculateMetrics (Graph$<$ Node $>$ $*$g) const

  Calculate metrics to assess the balance of water flow in a given graph. (T2.3)
- void evaluateReservoirImpact (const std::string &reservoir_code) const

  Evaluate the impact of removing a reservoir from the water supply network. (T3.1)
- void evaluateAllReservoirImpact () const

  Evaluate the impact of removing all reservoirs from the water supply network, one at a time. (T3.1)
- void evaluateAllPumpingStationImpact () const

  Evaluate the impact of removing all pumping stations from the water supply network, one at a time. (T3.1)
- void evaluatePipelineImpact (const std::string &city_code) const

  Evaluate the impact of removing pipelines on the water supply to a specific city. (T3.3)

Private Attributes

- Graph< Node > * network

4.6.1 Detailed Description

Class representing a water supply network.

This class provides functionality to model and analyze a water supply network, including methods for calculating maximum flow, evaluating network metrics, and managing network components.

4.6.2 Constructor & Destructor Documentation

4.6.2.1 WaterNetwork() [1/2]

```
WaterNetwork::WaterNetwork ( )
```

Default constructor for the WaterNetwork class.

4.6.2.2 WaterNetwork() [2/2]

```
WaterNetwork::WaterNetwork (
            const std::string reservoirs_filename,
            const std::string stations_filename,
            const std::string cities_filename,
            const std::string pipes_filename )
```

Constructor for the WaterNetwork class. This constructor initializes a water network graph by parsing data from provided files.

Parameters

reservoirs_filename	The filename of the CSV file containing reservoir data.
stations_filename	The filename of the CSV file containing station data.
cities_filename	The filename of the CSV file containing city data.
pipes_filename	The filename of the CSV file containing pipe data.

4.6.2.3 ∼WaterNetwork()

```
WaterNetwork::~WaterNetwork ( )
```

Destructor for the WaterNetwork class.

4.6.3 Member Function Documentation

4.6.3.1 calculateMetrics()

```
vector< pair< string, double > > WaterNetwork::calculateMetrics (
            Graph< Node > * g ) const
```

Calculate metrics to assess the balance of water flow in a given graph. (T2.3)

This function calculates various metrics to evaluate the balance of water flow in a provided graph. It assesses the difference between the weight of each edge (representing pipeline capacity) and its flow, both before and after attempting to balance the flow across the network.

The function first creates a super source and a super sink node in the graph and uses the Edmonds-Karp algorithm to find the maximum flow in the network. Then, it iterates over all edges in the graph to compute the differences between the edge weights and their corresponding flow values. These differences are used to calculate the maximum, average, and variance of the differences before attempting to balance the flow.

Next, the function attempts to balance the flow across the network by adjusting the flow in each pipeline. It identifies the pipeline with the maximum difference and the pipeline with the minimum difference and iteratively transfers flow from the maximum to the minimum until the differences are minimized.

After balancing the flow, the function recalculates the maximum, average, and variance of the differences.

Finally, the function stores the calculated metrics, including the maximum difference, average difference, and variance of differences before and after balancing, in a vector of pairs and returns it.

Parameters

g	Pointer to the graph for which metrics are to be calculated.

Returns

A vector of pairs containing the calculated metrics.

4.6.3.2 evaluateAllPumpingStationImpact()

```
void WaterNetwork::evaluateAllPumpingStationImpact ( ) const
```

Evaluate the impact of removing all pumping stations from the water supply network, one at a time. (T3.1)

This function assesses the consequences of removing each pumping station from the water supply network individually. It calculates the change in water flow to each city in the network before and after removing each pumping station.

To begin, the function computes the initial water flow to each city using the multiSinkMaxFlow function. Then, for each pumping station node in the network, it constructs a subgraph that contains only the connected component of the network excluding the pumping station. Subsequently, it determines the current maximum flow of water to each city within this subgraph. Finally, the function prints the impact of removing the pumping station by comparing the previous and current flows to each city and displaying any differences in water flow.

@complexity The time complexity of this function is O(V ∗ E^2 + V^2), where V is the number of vertices and E is the number of edges in the graph. This complexity arises from the operations performed to retrieve previous flow data, construct subgraphs for each pumping station, calculate current flows, and print the impact for each pumping station.

4.6.3.3 evaluateAllReservoirImpact()

```
void WaterNetwork::evaluateAllReservoirImpact ( ) const
```

Evaluate the impact of removing all reservoirs from the water supply network, one at a time. (T3.1)

This function assesses the consequences of removing each reservoir from the water supply network individually. It calculates the change in water flow to each city in the network before and after removing each reservoir.

To begin, the function computes the initial water flow to each city using the multiWaterNeeds function. Then, for each reservoir node in the network, it constructs a subgraph that contains only the connected component of the network including the reservoir. Subsequently, it determines the current maximum flow of water to each city within this subgraph. Finally, the function prints the impact of removing the reservoir by comparing the previous and current flows to each city and displaying any differences in water flow.

@complexity The time complexity of this function is O(V ∗ E^2 + V^2), where V is the number of vertices and E is the number of edges in the graph. This complexity arises from the operations performed to retrieve previous flow data, construct subgraphs for each reservoir, calculate current flows, and print the impact for each reservoir.

4.6.3.4 evaluatePipelineImpact()

```
void WaterNetwork::evaluatePipelineImpact (
            const std::string & city_code ) const
```

Evaluate the impact of removing pipelines on the water supply to a specific city. (T3.3)

This function assesses the impact of removing pipelines on the water supply to a specific city within the network. It calculates the change in water deficit for the specified city before and after removing each pipeline connected to it.

To begin, the function computes the initial water deficit for the city using the multiWaterNeeds function. Then, for each pipeline connected to the specified city, it temporarily removes the pipeline from the network, constructs a subgraph containing only the connected component of the network that includes the origin node of the pipeline, and calculates the current water deficit for the city in this subgraph.

If there is a change in water deficit for the city after removing the pipeline, it indicates that removing the pipeline impacts the water supply to the city, and the function prints the pipeline's origin and destination codes along with the magnitude of the impact. If there is no change in water deficit, it means that removing the pipeline does not affect the water supply to the city, and the function indicates this as well.

Parameters

city_code	The code of the city for which the impact of removing pipelines is to be evaluated.

@complexity The time complexity of this function depends on the size of the network and the number of pipelines connected to the specified city. For each pipeline, it constructs a subgraph, which has a complexity of O(V + E), where V is the number of vertices and E is the number of edges. Thus, the overall time complexity is O(V ∗ E + V ∗ E^2), where V is the number of vertices and E is the number of edges in the graph.

4.6.3.5 evaluateReservoirImpact()

```
void WaterNetwork::evaluateReservoirImpact (
            const std::string & reservoir_code ) const
```

Evaluate the impact of removing a reservoir from the water supply network. (T3.1)

This function calculates the impact of removing a reservoir specified by its code from the water supply network. It first validates the provided reservoir code to ensure it corresponds to a reservoir node in the network. Then, it determines the change in water flow to each city in the network before and after removing the reservoir. The function achieves this by calculating the maximum flow of water to each city using the multiSinkMaxFlow function.

After validating the reservoir code and calculating the initial flow, the function constructs a subgraph consisting only of the connected component of the network that includes the specified reservoir. It then recalculates the maximum flow of water to each city in this subgraph.

Finally, the function prints the impact of removing the reservoir by comparing the previous and current flows to each city and displaying the difference, if any, in water flow.

Parameters

reservoir_code	The code of the reservoir to be removed from the network.

Exceptions

std::runtime_error	if the provided reservoir code is not valid or does not correspond to a reservoir node in the network.

@complexity The time complexity of this function is O(V ∗ E^2), where V is the number of vertices and E is the number of edges in the graph. This complexity arises from the operations performed to retrieve previous flow data, construct the subgraph, and calculate the current flow to each city.

4.6.3.6 getNetworkGraph()

```
Graph< Node > * WaterNetwork::getNetworkGraph ( ) const
```

Getter for the network graph.

Returns

A pointer to the network graph.

4.6.3.7 multiSinkMaxFlow()

```
vector< pair< string, double > > WaterNetwork::multiSinkMaxFlow (
            Graph< Node > * g,
            const bool & flag ) const
```

Determine the maximum amount of water that can reach each city in the water supply network. (T2.1)

This function calculates the maximum flow of water that can reach each city in the water supply network. It uses the Edmonds-Karp algorithm to find the optimal flow through the network, with water reservoirs set as sources, delivery sites as sinks, and pumping stations as intermediate nodes. The function returns a vector of pairs containing each city's code and the corresponding maximum flow of water reaching it. Additionally, if the flag parameter is set to true, the function writes the results to a CSV file named "MaxFlow.csv" in the "out" directory.

Parameters

g	A pointer to the graph representing the water supply network.
flag	A boolean flag indicating whether to write the results to a CSV file (true) or not (false).

Returns

A vector of pairs, where each pair consists of a city code and the maximum flow of water reaching that city.

@complexity O(V $*$ E^2), where V is the number of vertices and E is the number of edges in the graph.

4.6.3.8 multiWaterNeeds()

```
vector< pair< string, double > > WaterNetwork::multiWaterNeeds (
            Graph< Node > * g,
            const bool & flag ) const
```

Determine the water deficit or excess for each city in the water supply network. (T2.2)

This function calculates the water deficit or excess for each city in the water supply network. It uses the Edmonds-Karp algorithm to find the optimal flow through the network, with water reservoirs set as sources, delivery sites as sinks, and pumping stations as intermediate nodes. The function returns a vector of pairs containing each city's code and the corresponding water deficit or excess. If the flag parameter is set to true, the function also writes the results to a CSV file named "WaterNeeds.csv" in the "out" directory.

Parameters

g	A pointer to the graph representing the water supply network.
flag	A boolean flag indicating whether to write the results to a CSV file (true) or not (false).

Returns

A vector of pairs, where each pair consists of a city code and the corresponding water deficit or excess.

@complexity O(V $*$ E^2), where V is the number of vertices and E is the number of edges in the graph.

4.6.3.9 singleSinkMaxFlow()

```
double WaterNetwork::singleSinkMaxFlow (
            const std::string & city_code ) const
```

Determine the maximum amount of water that can reach a specific city. (T2.1)

This function calculates the maximum flow of water that can reach a specified city in the water supply network. It uses the Edmonds-Karp algorithm to find the optimal flow through the network, with water reservoirs set as sources, delivery sites as sinks, and pumping stations as intermediate nodes. The flow reaching the specified city is then computed based on the flow of incoming edges to the city.

Parameters

city_code	The code of the city for which the maximum flow is to be determined.

Returns

The maximum flow of water that can reach the specified city.

@complexity O(V $*$ E^2), where V is the number of vertices and E is the number of edges in the graph.

4.6.4 Member Data Documentation

4.6.4.1 network

```
Graph<Node>* WaterNetwork::network [private]
```

The documentation for this class was generated from the following files:

- inc/WaterNetwork.hpp
- src/WaterNetwork.cpp

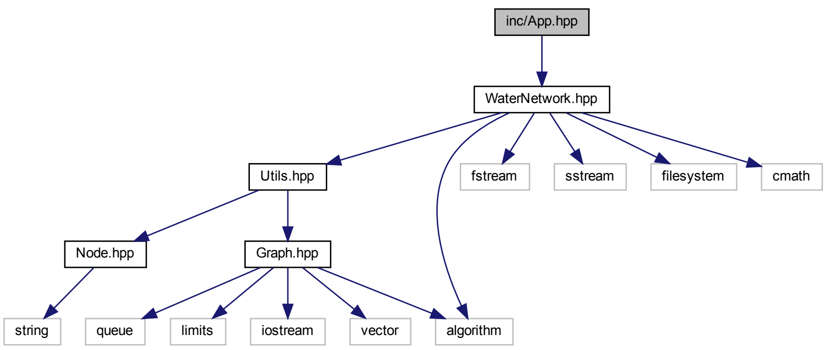
Chapter 5

File Documentation

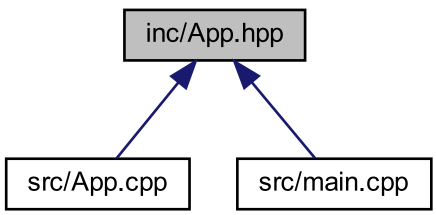
5.1 inc/App.hpp File Reference

`#include "WaterNetwork.hpp"`

Include dependency graph for App.hpp:



This graph shows which files directly or indirectly include this file:



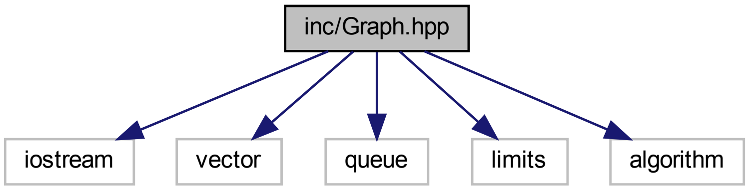
Classes

- class App

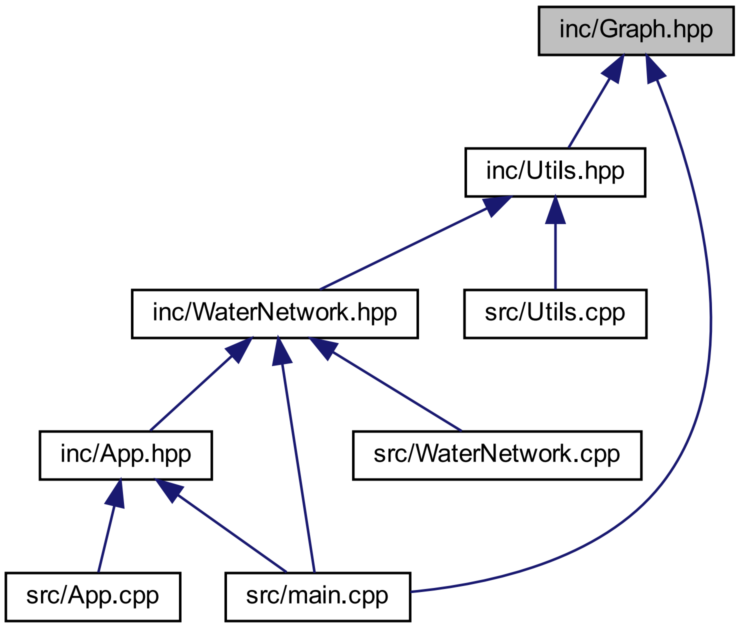
5.2 inc/Graph.hpp File Reference

```
#include <iostream>
#include <vector>
#include <queue>
#include <limits>
#include <algorithm>
```

Include dependency graph for Graph.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class Vertex< T >
- class Edge< T >
- class Graph< T >

Macros

- #define INF std::numeric_limits<double>::max()

5.2.1 Macro Definition Documentation

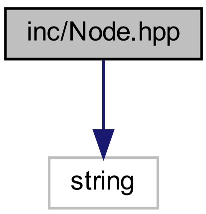
5.2.1.1 INF

```
#define INF std::numeric_limits<double>::max()
```

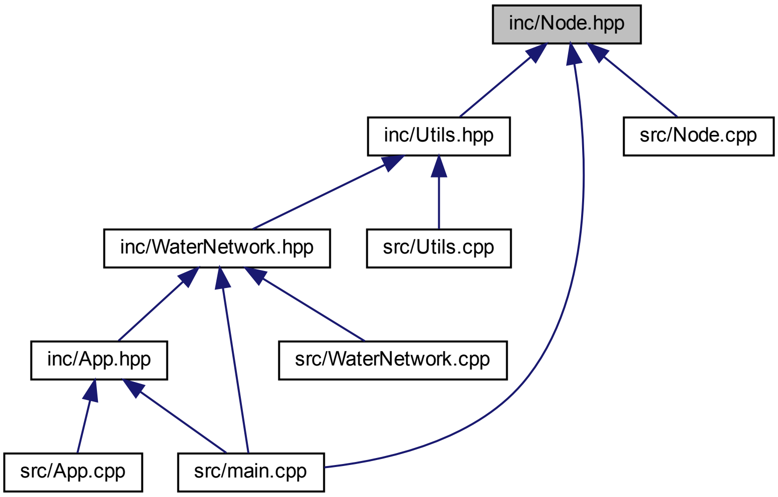
5.3 inc/Node.hpp File Reference

```
#include <string>
```

Include dependency graph for Node.hpp:



This graph shows which files directly or indirectly include this file:



Classes

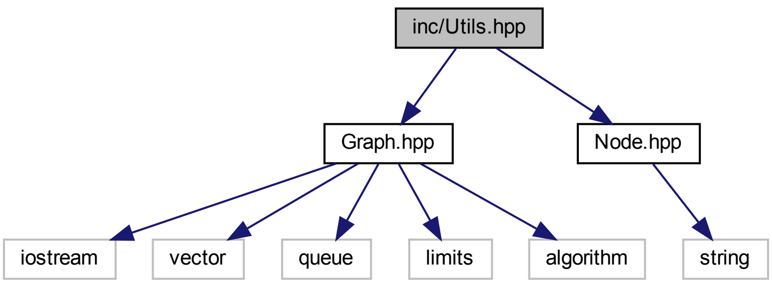
- class Node

    Represents a node in a network.

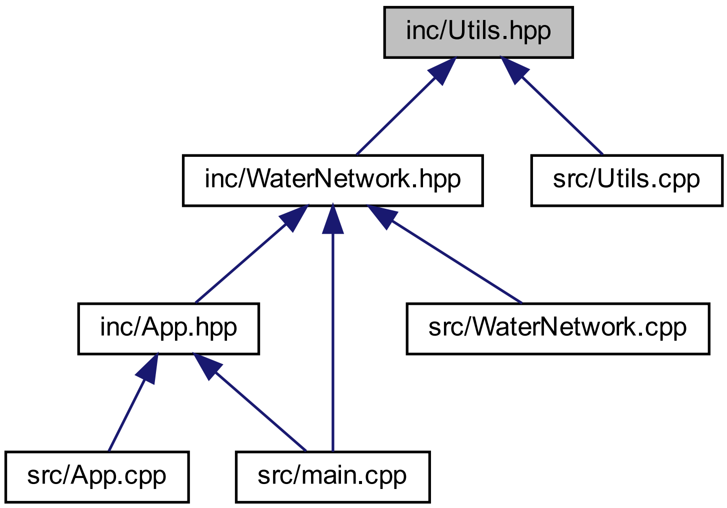
5.4 inc/Utils.hpp File Reference

```
#include "Graph.hpp"
#include "Node.hpp"
```

Include dependency graph for Utils.hpp:



This graph shows which files directly or indirectly include this file:



Functions

- void testAndVisit (std::queue< Vertex< Node > * > &q, Edge< Node > *e, Vertex< Node > *w, double residual)

  Helper function to test and visit vertices during BFS traversal.
- bool findAugmentingPath (Graph< Node > *g, Vertex< Node > *s, Vertex< Node > *t)

  Function to find an augmenting path in the graph using BFS.
- double findMinResidualAlongPath (Vertex< Node > *s, Vertex< Node > *t)

  Function to find the minimum residual capacity along an augmenting path.
- void augmentFlowAlongPath (Vertex< Node > *s, Vertex< Node > *t, double f)

  Function to augment flow along an augmenting path.
- void edmondsKarp (Graph< Node > *g, Node source, Node target)

  Function implementing the Edmonds-Karp algorithm for maximum flow.
- void resetGraph (Graph< Node > *g, const Node &s, const Node &t)

  Function to reset the state of the graph.
- Node createSuperSource (Graph< Node > *g)

  Function to create a super source node in the graph.
- Node createSuperSink (Graph< Node > *g)

  Function to create a super sink node in the graph.
- bool comparePipes (const std::pair< Edge< Node > *, double > &a, const std::pair< Edge< Node > *, double > &b)

  Compare function for sorting pipes based on their difference.
- void dfsVisitFindCC (Vertex< Node > *v, std::vector< Vertex< Node > * > &res)

  Depth-first search visit function to find connected components.
- Graph< Node > * findConnectedComponent (Graph< Node > *g, const std::string &node_code)

  Find connected component containing a specific node.

5.4.1 Function Documentation

5.4.1.1 augmentFlowAlongPath()

```
void augmentFlowAlongPath (
            Vertex< Node > * s,
            Vertex< Node > * t,
            double f )
```

Function to augment flow along an augmenting path.

This function traverses the augmenting path from the target vertex to the source vertex and updates the flow values of edges and current flow values of vertices accordingly.

Parameters

s	The source vertex.
t	The target vertex.
f	The flow value to augment along the path.

@complexity O(V)

5.4.1.2 comparePipes()

```
bool comparePipes (
            const std::pair< Edge< Node > *, double > & a,
            const std::pair< Edge< Node > *, double > & b )
```

Compare function for sorting pipes based on their difference.

This function is used as a comparison criterion for sorting pipes based on their difference values. It takes two pairs containing a pointer to an edge representing a pipe and its corresponding difference value. It returns true if the difference of the first pair is greater than the difference of the second pair, indicating that the first pipe should be placed before the second pipe in the sorted sequence.

Parameters

a	The first pair containing a pointer to an edge and its difference value.
b	The second pair containing a pointer to an edge and its difference value.

Returns

True if the difference of the first pair is greater than the difference of the second pair, false otherwise.

5.4.1.3 createSuperSink()

```
Node createSuperSink (
            Graph< Node > * g )
```

Function to create a super sink node in the graph.

This function creates a super sink node in the graph with maximum demand capacity. It adds edges from all city nodes in the graph except itself to the super sink.

Parameters

g	The graph to add the super sink node.

Returns

The super sink node created.

@complexity O(V)

5.4.1.4 createSuperSource()

```
Node createSuperSource (
            Graph< Node > * g )
```

Function to create a super source node in the graph.

This function creates a super source node in the graph with maximum delivery capacity. It adds edges from the super source to all reservoir nodes in the graph except itself.

Parameters

g	The graph to add the super source node.

Returns

The super source node created.

@complexity O(V)

5.4.1.5 dfsVisitFindCC()

```
void dfsVisitFindCC (
            Vertex< Node > * v,
            std::vector< Vertex< Node > * > & res )
```

Depth-first search visit function to find connected components.

This function performs a depth-first search (DFS) traversal starting from a given vertex to find all connected components in the graph. It marks visited vertices and adds them to the result vector.

During the traversal, if the adjacent vertex 'w' is either a Pumping Station (type 1) or a city (type 2), the DFS traversal continues recursively from 'w' to explore further connected vertices. Otherwise, if 'w' is a Reservoir (type 0), it is marked as visited and added to the result vector.

Parameters

v	The vertex to start the DFS traversal from.
res	The vector to store the visited vertices representing the connected component.

@complexity O(V + E), where V is the number of vertices and E is the number of edges in the graph.

5.4.1.6 edmondsKarp()

```
void edmondsKarp (
            Graph< Node > * g,
            Node source,
            Node target )
```

Function implementing the Edmonds-Karp algorithm for maximum flow.

This function finds the maximum flow in the graph from a source vertex to a target vertex using the Edmonds-↩ Karp algorithm. It repeatedly finds augmenting paths using BFS and augments flow along the paths until no more augmenting paths exist.

Parameters

g	The graph representing the water network.
source	The source node.
target	The target node.

@complexity O(V ∗ E^2)

5.4.1.7 findAugmentingPath()

```
bool findAugmentingPath (
            Graph< Node > * g,
            Vertex< Node > * s,
            Vertex< Node > * t )
```

Function to find an augmenting path in the graph using BFS.

This function marks all vertices as not visited, marks the source vertex as visited, and performs BFS traversal to find an augmenting path from the source to the target vertex. It returns true if a path to the target vertex is found, and false otherwise.

Parameters

g	The graph to search for augmenting paths.
s	The source vertex.
t	The target vertex.

Returns

True if an augmenting path is found, false otherwise.

@complexity O(V + E)

5.4.1.8 findConnectedComponent()

```
Graph<Node>* findConnectedComponent (
            Graph< Node > * g,
            const std::string & node_code )
```

Find connected component containing a specific node.

This function finds the connected component in the graph that contains the specified node. It performs a depth-first search (DFS) traversal from the specified node to identify the connected component.

The function constructs a subgraph representing the connected component by adding edges from the original graph based on the connections of vertices within the connected component.

Parameters

g	The graph to search for the connected component.
node_code	The code of the node indicating the connected component to find.

Returns

A pointer to the subgraph representing the connected component containing the specified node.

Exceptions

std::runtime_error	if the specified node code is not found in the graph.

@complexity O(V + E), where V is the number of vertices and E is the number of edges in the graph.

5.4.1.9 findMinResidualAlongPath()

```
double findMinResidualAlongPath (
            Vertex< Node > * s,
            Vertex< Node > * t )
```

Function to find the minimum residual capacity along an augmenting path.

This function traverses the augmenting path from the target vertex to the source vertex to find the minimum residual capacity. It considers the capacity of edges and the demand of cities.

Parameters

s	The source vertex.
t	The target vertex.

Returns

The minimum residual capacity along the augmenting path.

@complexity O(V)

5.4.1.10 resetGraph()

```
void resetGraph (
            Graph< Node > * g,
            const Node & s,
            const Node & t )
```

Function to reset the state of the graph.

This function resets the state of the graph by marking all vertices as not visited, clearing paths, current flow, and used delivery. It also resets the flow of all edges to zero. Additionally, it removes the super source and super sink nodes from the graph.

Parameters

g	The graph to reset.
s	The super source node to remove.
t	The super sink node to remove.

@complexity O(V + E)

5.4.1.11 testAndVisit()

```
void testAndVisit (
            std::queue< Vertex< Node > * > & q,
            Edge< Node > * e,
            Vertex< Node > * w,
            double residual )
```

Helper function to test and visit vertices during BFS traversal.

This function checks if the vertex 'w' is not visited and there is residual capacity. If so, it marks 'w' as visited, sets the path through which it was reached, and enqueues it.

Parameters

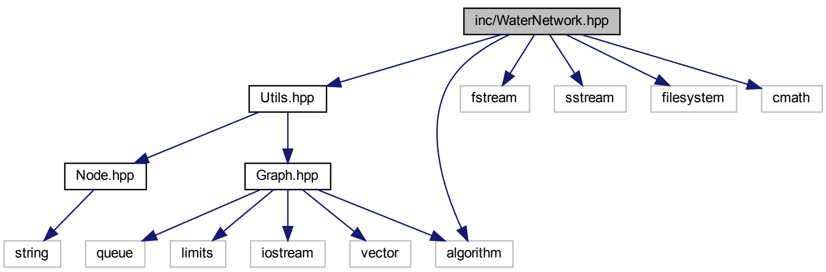
q	The queue of vertices to visit.
e	The edge connecting the current vertex to 'w'.
w	The vertex to visit.
residual	The residual capacity of the edge connecting the current vertex to 'w'.

@complexity O(1)

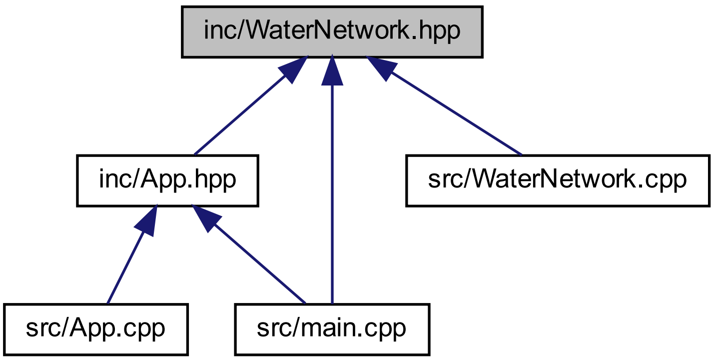
5.5 inc/WaterNetwork.hpp File Reference

```
#include "Utils.hpp"
#include <algorithm>
#include <fstream>
#include <sstream>
#include <filesystem>
#include <cmath>
```

Include dependency graph for WaterNetwork.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class WaterNetwork

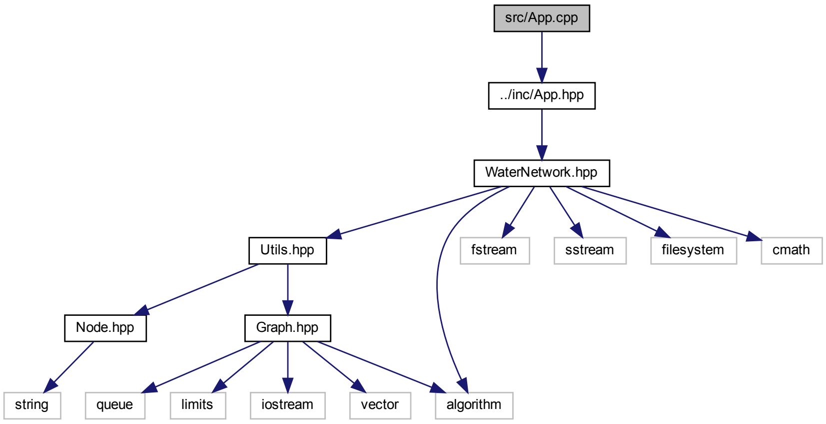
  Class representing a water supply network.

5.6 README.md File Reference

5.7 src/App.cpp File Reference

```
#include "../inc/App.hpp"
```

Include dependency graph for App.cpp:



Functions

- void clearScreen ()

5.7.1 Function Documentation

5.7.1.1 clearScreen()

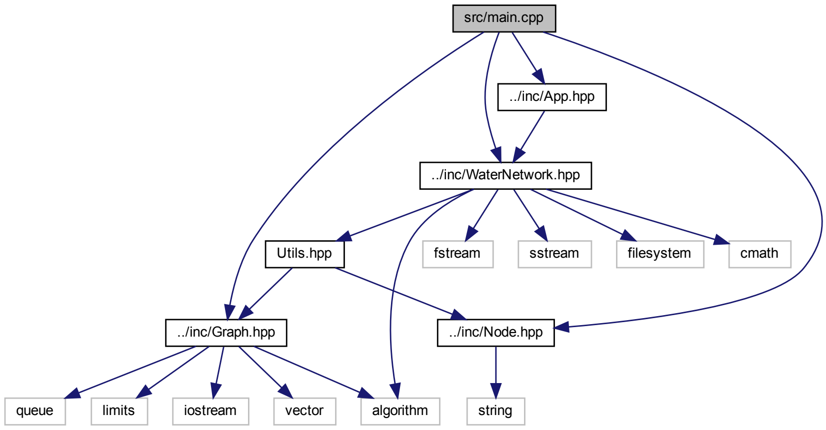
```
void clearScreen ( )
```

5.8 src/main.cpp File Reference

```
#include "../inc/Graph.hpp"
#include "../inc/Node.hpp"
#include "../inc/WaterNetwork.hpp"
```

```
#include "../inc/App.hpp"
```

Include dependency graph for main.cpp:



Functions

- int main ()

5.8.1 Function Documentation

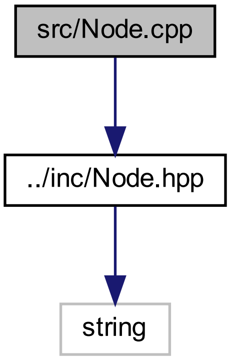
5.8.1.1 main()

```
int main ( )
```

5.9 src/Node.cpp File Reference

`#include "../inc/Node.hpp"`

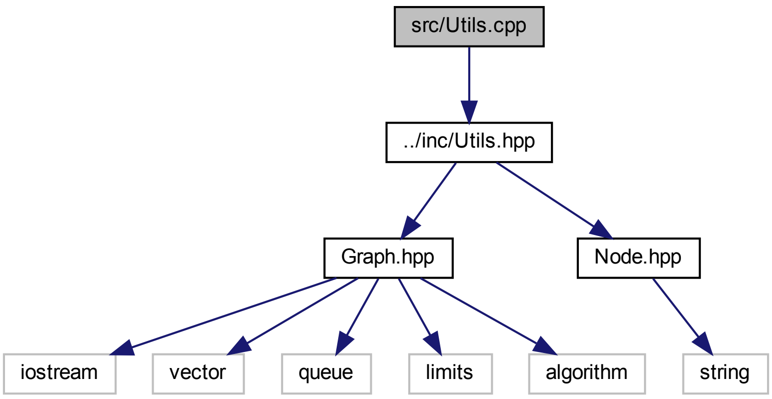
Include dependency graph for Node.cpp:



5.10 src/Utils.cpp File Reference

`#include "../inc/Utils.hpp"`

Include dependency graph for Utils.cpp:



Functions

- void testAndVisit (queue< Vertex< Node > ∗ > &q, Edge< Node > ∗e, Vertex< Node > ∗w, double residual)

- bool findAugmentingPath (Graph< Node > *g, Vertex< Node > *s, Vertex< Node > *t)

  Function to find an augmenting path in the graph using BFS.
- double findMinResidualAlongPath (Vertex< Node > *s, Vertex< Node > *t)

  Function to find the minimum residual capacity along an augmenting path.
- void augmentFlowAlongPath (Vertex< Node > *s, Vertex< Node > *t, double f)

  Function to augment flow along an augmenting path.
- void edmondsKarp (Graph< Node > *g, Node source, Node target)

  Function implementing the Edmonds-Karp algorithm for maximum flow.
- void resetGraph (Graph< Node > *g, const Node &s, const Node &t)

  Function to reset the state of the graph.
- Node createSuperSource (Graph< Node > *g)

  Function to create a super source node in the graph.
- Node createSuperSink (Graph< Node > *g)

  Function to create a super sink node in the graph.
- bool comparePipes (const pair< Edge< Node > *, double > &a, const pair< Edge< Node > *, double > &b)
- void dfsVisitFindCC (Vertex< Node > *v, vector< Vertex< Node > * > &res)
- Graph< Node > * findConnectedComponent (Graph< Node > *g, const string &node_code)

5.10.1 Function Documentation

5.10.1.1 augmentFlowAlongPath()

```
void augmentFlowAlongPath (
            Vertex< Node > * s,
            Vertex< Node > * t,
            double f )
```

Function to augment flow along an augmenting path.

This function traverses the augmenting path from the target vertex to the source vertex and updates the flow values of edges and current flow values of vertices accordingly.

Parameters

s	The source vertex.
t	The target vertex.
f	The flow value to augment along the path.

@complexity O(V)

5.10.1.2 comparePipes()

```
bool comparePipes (
            const pair< Edge< Node > *, double > & a,
            const pair< Edge< Node > *, double > & b )
```

5.10.1.3 createSuperSink()

```
Node createSuperSink (
            Graph< Node > * g )
```

Function to create a super sink node in the graph.

This function creates a super sink node in the graph with maximum demand capacity. It adds edges from all city nodes in the graph except itself to the super sink.

Parameters

g	The graph to add the super sink node.

Returns

The super sink node created.

@complexity O(V)

5.10.1.4 createSuperSource()

```
Node createSuperSource (
            Graph< Node > * g )
```

Function to create a super source node in the graph.

This function creates a super source node in the graph with maximum delivery capacity. It adds edges from the super source to all reservoir nodes in the graph except itself.

Parameters

g	The graph to add the super source node.

Returns

The super source node created.

@complexity O(V)

5.10.1.5 dfsVisitFindCC()

```
void dfsVisitFindCC (
            Vertex< Node > * v,
            vector< Vertex< Node > * > & res )
```

5.10.1.6 edmondsKarp()

```
void edmondsKarp (
            Graph< Node > * g,
            Node source,
            Node target )
```

Function implementing the Edmonds-Karp algorithm for maximum flow.

This function finds the maximum flow in the graph from a source vertex to a target vertex using the Edmonds-Karp algorithm. It repeatedly finds augmenting paths using BFS and augments flow along the paths until no more augmenting paths exist.

Parameters

g	The graph representing the water network.
source	The source node.
target	The target node.

@complexity O(V ∗ E^2)

5.10.1.7 findAugmentingPath()

```
bool findAugmentingPath (
            Graph< Node > * g,
            Vertex< Node > * s,
            Vertex< Node > * t )
```

Function to find an augmenting path in the graph using BFS.

This function marks all vertices as not visited, marks the source vertex as visited, and performs BFS traversal to find an augmenting path from the source to the target vertex. It returns true if a path to the target vertex is found, and false otherwise.

Parameters

g	The graph to search for augmenting paths.
s	The source vertex.
t	The target vertex.

Returns

True if an augmenting path is found, false otherwise.

@complexity O(V + E)

5.10.1.8 findConnectedComponent()

```
Graph<Node>* findConnectedComponent (
            Graph< Node > * g,
            const string & node_code )
```

5.10.1.9 findMinResidualAlongPath()

```
double findMinResidualAlongPath (
            Vertex< Node > * s,
            Vertex< Node > * t )
```

Function to find the minimum residual capacity along an augmenting path.

This function traverses the augmenting path from the target vertex to the source vertex to find the minimum residual capacity. It considers the capacity of edges and the demand of cities.

Parameters

s	The source vertex.
t	The target vertex.

Returns

The minimum residual capacity along the augmenting path.

@complexity O(V)

5.10.1.10 resetGraph()

```
void resetGraph (
            Graph< Node > * g,
            const Node & s,
            const Node & t )
```

Function to reset the state of the graph.

This function resets the state of the graph by marking all vertices as not visited, clearing paths, current flow, and used delivery. It also resets the flow of all edges to zero. Additionally, it removes the super source and super sink nodes from the graph.

Parameters

g	The graph to reset.
s	The super source node to remove.
t	The super sink node to remove.

@complexity O(V + E)

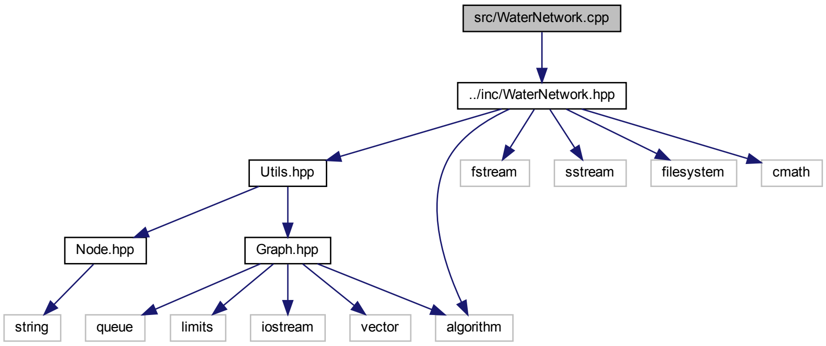
5.10.1.11 testAndVisit()

```
void testAndVisit (
            queue< Vertex< Node > * > & q,
            Edge< Node > * e,
            Vertex< Node > * w,
            double residual )
```

5.11 src/WaterNetwork.cpp File Reference

```
#include "../inc/WaterNetwork.hpp"
```

Include dependency graph for WaterNetwork.cpp:



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