AND TECHNOLOGY I ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING

PhD Yearbook | 2017



DOCTORAL PROGRAM IN ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING

Chair: Prof. Alberto Guadagnini

The Doctorate in Environmental and Infrastructure Engineering has been operating since the academic year 2008/2009. The program introduces doctoral students to the world of research on key theoretical and technological elements associated with water, environment, hydraulic and transportation infrastructures, geology, as well as geomatics. In this context, the program is grounded on environmental, civil, and industrial applications where water is the primary unifying element. The doctorate program is characterized by a strong inter- and multidisciplinary structure and is organized according to the following key thematic areas.

- Hydraulic Engineering, where major research themes include: fluid mechanics; fluid-structure interactions; hydraulic measurements; river hydraulics; sediment mechanics; hydraulic risk assessment and management; flow and transport processes in porous systems; hydraulic networks, hydro-energy; oil and gas development and applications.
- 2. Hydrology, hydraulic structures, water resources and coastal engineering, where the main research topics include: hydrology and water resources, with emphasis on the main physical processes of the hydrological cycle, water and energy budgets; hydrogeological hazard and mitigation strategies, including hydrological extremes, floods, droughts and precipitation, early warning operative systems, snow avalanching and flood risk; hydraulic networks engineering; and coastal engineering.
- 3. *Environmental technologies*, with focus on: water and wastewater treatment technologies (including disposal/reuse of wastewater, sludge management and disposal, anaerobic digestion processes; management and planning of environmental resources (including water quality modelling, knowledge-based decision support systems); solid wastes management (including Life Cycle Assessment of energy and resource recovery initiatives); phenomenology of the atmospheric environment and treatment of gaseous emissions; contaminated soils and their remediation.
- 4. *Transport infrastructures and geology*, with focus on: transport networks, including functional interactions with regional, national and international territory; sustainable development, in terms of

dynamics of development and its relations with the infrastructure system; technological innovation, including methods and indicators for performance characterization of infrastructure construction and maintenance techniques; hydrogeological risk, landslide hazard; water resources identification and management, pollution problems.

5. Geomatics, with focus on: physical geodesy and satellite geodesy; positioning and navigation; surface surveying with optical or other sensors, such as SAR, LIDAR; digital photogrammetry and image analysis; remote sensing; geographic information systems; cultural heritage reconstruction and archiving. The curriculum of PhD students has been tailored to the general and specific research questions associated with the multifaceted interactions between the water sphere and the key evolving anthropogenic activities responding to the needs of modern society.

Career perspectives include opportunities at Universities, Research Centers, public bodies and Authorities, as well as private companies / industry. Small and medium size enterprises (SMEs) which cannot afford the development of an in-house specific know-how program may also require such highly professional profiles to guarantee critical innovation and competitiveness.

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ENVIRONMENTAL

NEW METHODS IN ROAD ASSET MANAGEMENT SYSTEMS: MONITORING OF PAVEMENT CONDITIONS AND INCORPORATION OF RISK ASSESSMENT

Alberti Susanna - Supervisor: Prof. Maurizio Crispino

Pavement Management Systems (PMS) are useful tools for road agencies to focus on the real needs of a network during its service life and provide a systematic method to determine the right action at the right time, under different budget scenarios.

In Italy an actual PMS does not exist (due to many and complex issues) and there is a need to simplify road management and spread the basic knowledge on PMS.

At an international level, effective examples of Pavement Management Systems (PMS) that develop optimization methods of the available resources can be found, allowing an identification of the best action strategies over the reference time frame (planning). The first step of this work focused on the situation in Lombardy region, analysing the allocated resources for routine maintenance, major rehabilitation and network expansion; financial constraints and lack of maintenance planning were identified as the main issues of poor pavement conditions. The aim of this PhD thesis was to provide Italian road managers (both highway agencies and local authorities) with different procedures, developing useful tools to better manage their road networks. Guidelines to develop pavement deterioration

models were drafted, focusing on a case study on two Italian highways. Road inspections were carried out for seven consecutive years, in collaboration with a monitoring company, and friction, macrotexture and roughness data were collected with highspeed vehicles. The trend of each characteristic over time was then studied and justified at a project level of the maintenance management, based on the recorded treatments. The experimental program was divided into different steps. Milestone 1 included the identification of homogenous road sectors in terms of traffic levels (Annual Average Daily Traffic - AADT), pavement structure, materials and driving directions. Four macro-sectors with homogeneous traffic levels were identified and traffic data were converted into ESALs (Equivalent Single Axle Loads) and then into cumulative ESALs (CESALs) to relate damage assessment to pavement age and traffic loading. The second step (Milestone 2) was to identify homogeneous sections within the macro-sectors in terms of collected friction (Side Force Coefficient), macrotexture (Mean Profile Depth) and roughness (International Roughness Index) data. Adjustments were conducted due to odometer shifts that caused offsets of the data reference point from year to year. A segmentation process based on clustering analysis was performed, using differences in the moving average to evaluate the initial/final limit of the statistical homogeneous sections. In Milestone 3 upper and lower guartiles were computed in order to remove all the outliers which could potentially affect the analysis. In Milestone 4 degradation models and equations were defined by taking into account pavement specific condition, age and cumulative ESALs: the trend of each characteristic was then studied and justified at a project level of the maintenance management, based on the recorded treatments. Milestone 5 showed surface charts, with pavement condition as a function of age and average annual traffic on the road. Setting acceptability thresholds, the work provides tables as decision making support for road managers. A useful flow chart was also defined to help road agencies in preserving their assets To help local authorities in preserving their assets and

to simplify the pavement management process, risk was also incorporated, introducing the basic knowledge of risk assessment and multi criteria analysis. Innovative concepts of levels of service were developed; risk mitigation was studied and optimization techniques were used to define a Risk/Cost ratio to select the best intervention strategy. The work was fully calibrated on the Italian road network, starting from a new road classification that reflects the actual maintenance needs. Risk assessment was used to get: a proper functional classification of the existing road network, knowledge of the condition/level of maintenance on the managed roads, effective communication to road users, optimal selection of maintenance strategies and rational use of the available economic resources. The research program followed five steps. In Milestone 1 road maintenance classes and target maintenance levels of service (LSMob) were defined, while in Milestone 2 a Risk Score and actual maintenance levels of service (LSMeff) were developed. In Milestone 3 risk mitigation was then studied, setting type and time for intervention; in Milestone 4 all the constraints to reach the target maintenance level of service were identified and an analysis of the necessary budget to move from the actual (LSMeff) to the target maintenance level of service (LSMob) was performed. Using optimization techniques, Milestone 5 defined a Risk/Cost ratio to select the best preservation strategy and the work was concluded with a useful decision making tool for road agencies, a Microsoft Excel worksheet able to support the entire process. Since each road is characterized

target and actual maintenance

Since each road is characterized by a different risk exposure,

four elements (inputs) were taken into account to classify road maintenance classes (outputs): extension, traffic loads, population, functional importance of the connection/land use. Each element gave a partial score to the infrastructure, while the total score defined the road maintenance class. For this step, calibration and validation were the most important issues. Five classes and three target maintenance levels of service were considered for the road rating. To establish a Risk Score, an accident risk matrix and a distress risk matrix were developed, showing four different probability and consequence levels for highways and other assets (minor collectors). To establish risk thresholds, probability density functions of accident frequencies and injuries were analyzed, together with a global condition index (Pavement Condition Index - PCI) and a probability score for road failure (including pavement age, traffic, rainfall exposure, temperature ranges, landslides hazard, earthquake hazard, distance from rivers, geological conditions, topography, diggings or constructions by the sides, at-grade intersections, public transport). Merging an accident Risk Score (RSINC) and a distress Risk Score (RSDIS), a weighted total Risk Score was obtained, defining the actual maintenance level of service (LSMeff). Frequencies of inspection were provided and four groups of treatments were applied to mitigate risk: preventive maintenance, routine maintenance, minor and major

rehabilitation. All the constraints to reach target maintenance levels of service were studied for the road maintenance classes; charts assessing the goal achievement were also given to road agencies. Minimum and maximum unit costs to gain the target maintenance level of service were then evaluated.

Six pre-set maintenance strategies and two goals were considered; by asking road agencies to input well known information, the risk management tool provides them with the value of Risk/ Cost ratio and the outcomes that best fit the available budget, a maintenance plan that minimizes risk and maximizes pavement performances. In future the results obtained using this tool will also allow researchers to better understand the relationship between accident rate and road pavement conditions, filling the gaps in literature.

THE EFFECT OF WEATHER ON USER-GENERATED BIG GEO DATA IN MOBILE PHONE NETWORKS: CASE STUDY IN MILAN ITALY

Arias Muñoz Carolina - Supervisor: Prof. Maria Antonia Brovelli

Telecommunications Data are typically used as proxies for human activity and mobility, and it is used to solved a wide range of problems including energy consumption, mobility planning, tourism, urban dynamics, event detection, urban well-being and many others. In not so many studies, the relationship between environmental variables and mobile traffic data have been explored. Furthermore, the geospatial distribution of Telecommunications Data is not taken into consideration as an important aspect of the analysis. Because of its many applications, Telecommunications Data can be a valuable tool to understand cities. In Smart Cities domain, there is an opportunity to exploit these data for supporting decision making and collectively plan for the future of the cities. In the future, research is needed to focus on behavioral patterns, building analytics and systems to process massive data sets and automatically extract patterns, to finally build control systems able to use inferred patterns to optimize city services. Taking into account the above, this work explores if there is any relationship between precipitation levels and Call Detail Records CDR in the city of Milan, as a first approach towards an

understanding of city dynamics and human behavior regarding weather conditions. The main hypothesis is that there is an influence of weather conditions on mobile phone usage, which could allow detecting - to some extent - events related to high precipitation levels at a city scale. The drive to this assumption is the fact that the coverage of Mobile Radio Base Stations RBS is more ubiguitous than the presence of weather stations. This could lead in the future to possible applications such as a predictive model for weather conditions/ environmental stress from telecommunications data. This work was developed considering: a) The use of available Open Data, b) The use of only Free and Open Source Software, c) The use of technologies to deal with Big Data, d) The of use of parametric and non-parametric statistical analysis such as the analysis of variance, and e) The geospatial distribution of the data. The used data in this work corresponds to mobile telecommunications records between November and December 2013 of the city of Milan, available to the public under the Open Database License (ODbL) at https://dandelion.eu/

datamine/open-big-data/. The

datasets are user-generated

telecommunication traffic. corresponding to the result of computation over the Call Detail Records (CDR) of sent and received SMS, incoming and outgoing calls, and Internet traffic. A CDR represents the number of mobile phones simultaneously using the network at a given moment. All Datasets have a temporal aggregation of ten minutes, being in total 14'877.485 records. Data is provided in 60 Comma Separated Values CSV files, each containing one day of records, and a square grid (100 columns by 100 rows) covering the city of Milan and some of its surroundings, with a square cell size of 235 meters. Telecommunications data in the city of Milan behaves in a weekly seasonality between working days and weekends as well as working and non-working hours. High CDR values concentrate on the urban areas in the center of the city, where they cluster together and share a high spatial autocorrelation (see fig.1). The found peaks in the data are explained by special events and activities like Christmas and New Year's Eve. All this suggests that the data correctly reflects the spatiotemporal human patterns in the city of Milan, meaning that the data is highly representative to carry out the proposed analysis.



1. Mean (a) and maximum(b) values of Outgoing calls in the city of Milan between November – December 2013

Precipitation data was used to represent the weather factor. The interpolated precipitation maps of November and December 2013 used in this work, come from Lombardy's Regional Agency for Environmental Protection ARPA. In this work, only Free and Open Source Software was used. Data processing and preprocessing was done with Python, R language, GRASS GIS, while for data-storage MongoDB, GRASS GIS Database, and RASDAMAN were used. Their interoperability was demonstrated, along



2. Radial box plot of incoming calls in the city of Milan a) between 11/29/13 and 12/05/13 (normal week) b) between 12/25/13 and 12/31/13 (last week of the year, New Year's Eve).

with their functionalities and potentialities for dealing with Big Geo data. NoSQL databases like MongoDB and frameworks like RASDAMAN could offer different functionalities that facilitate working with larger volumes and more heterogeneous geospatial data sources. All code created for this work. from data preprocessing to data visualization is available on GitHub at https://github.com/ carolinarias/Sensing-the-City/, under an MIT license. According to the ANOVA and Kruskal-Wallis test results. we can conclude that for a confidence interval (95%) the null hypothesis of equality of medians can be rejected: there is a significant relationship between telecommunications data and precipitation intensity levels. The results are a promising step towards a holistic understanding of the complex relationship between environmental and social dynamics, and a starting point for further smart cities analysis.

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WATER RESOURCES MANAGEMENT AND COST EFFICIENCY ANALYSIS OF DIFFERENT SCENARIOS

Çevirgen Serap - Supervisor: Dr. Arianna Azzellino

Water resources management is a complex issue since it bears many challenges to be resolved and addressed explicitly. Today, we are more concerned than ever to manage earth's resources in a sustainable way. Naturally uneven distributed water resources have potential to create stress over water-poor areas in the world, and water scarcity seems to be the biggest fear of human kind nowadays. Water quality, in fact, is as important as water quantity. It is actually the first condition to be realized when dealing with the management of water resources since poor quality conditions of water resources affect ecosystem functioning in the habitats of many aquatic species and their surrounding environments as a chain. Once we cannot reach the good water quality in our water bodies we cannot proceed in any way to utilize continuously this vital resource. There have always been water

laws in order to comply with the necessary water quality criteria. These laws sometimes stressed discharge limits for the receiving water bodies and, sometimes required treatment of pollutants at the source. With the advent of Water Framework Directive in 2000 the necessity of an integrated and co-ordinated approach while managing water resources

became inevitable. The coordinated approach requires the formation of river basin districts and following management plans for every district. These plans must involve watershed specific measures which must be tailored according to needs of the land and the water bodies. The indispensable step in this procedure is the identification of prevailing stressors in the undertaken area. In other words, right diagnosis is essential for the right treatment. Water Framework Directive adopts a holistic approach towards the sustainable management of all types of inland waters, and coastal waters. The very crucial and important phase of this management cycle is the identification of pressures and stressors that are acting directly or indirectly on the status of water resources and, development of appropriate measures for the purposes of full or partial restoration goals. Development of tools and methods is crucial in order to find out the most effective restoration measure. Especially quantitative computer modelling is one of the most useful tools in terms of projection of future scenarios where the water resources can be maintained in their natural integrity. Scenario analyses provide great help in finding the most cost-effective

alternative in proposed restoration proposals.

This doctoral dissertation focuses on water resources management in the perspective of developing tools and methods and, measuring the effectiveness and/or costeffectiveness of various scenarios in an attempt to support decision making process. The research is organized on a case study basis; each case study represents a different water body in terms of geography and physico-chemical properties. The aim was to analyse and understand underlying factors that are affecting the system's integrity and propose meaningful set of restoration goals. For this purpose we utilized different quantitative models. First case study is a very particular river system in the northern part of Lombardy region. Lambro-Seveso-Olona river system, well known being the most polluted tributary of Italy's longest river Po; it was modelled through the USEPA QUAL2K model, allowing to consider various scenarios for improving the quality status of the system and to evaluate them in terms of cost and effectiveness. Second case concerns the Venice Lagoon and its watershed which were analysed through SWAT (Soil and Water Assessment Tool, USDA Model) and Aquatox (USAEPA model) models. While

SWAT enabled to apportion the different sources of nutrient load in the watershed. Aquatox enabled to evaluate the trophic status of the Lagoon taking into account the same loads coming from the watershed. In addition, a meta-model was also developed using a neural network approach on the basis of SWAT outputs. The aim was to develop a neural network capable to provide scenario predictions as accurate as the SWAT model but obtained, in shorter time thanks to both the higher computational efficiency and the quickest scenario implementation. Finally, in the last case study multivariate statistical methods were used in order to disentangle the multiple pressures and stresses, affecting the water resources of whole Lombardy region.

Colombo Loris - Supervisor: Dr. Luca Alberti

The problem of groundwater resources degradation in highly urbanized areas, during last two decades, is one of the most important environmental issues at both European and National level. In Italy, the Po plain, and in particular the Lombardy Region, is one of the most densely populated European areas where human activities have caused a tremendous impact on the groundwater quality. Nowadays, thanks to EU legislation, public authorities drive continue environmental monitoring activities that led to the creation of databases available for the study and resolution of environmental protection problems. In recent years, the new and recent National and Regional regulations consider the necessity to develop plans for the remediation and management of the most industrialized areas, affected by groundwater contamination due to both point sources (PS, associated with medium sources dimensions, i.e. hot-spots) and multiple point sources (MPS, constituted by a series of unidentifiable small sources clustered in a large area, that cause a diffuse contamination).

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The latter category predominates in European Functional Urban Areas and cannot be managed with remediation techniques

such as those commonly used for large/medium contaminated sites, mainly because of the difficulty to identify the many different source areas that release small contaminant mass. Consequently, the usual remediation procedures are not economically sustainable and often fail to provide results in an acceptable time frame. The Italian Law 152/2006 holds the definition of diffuse contamination: "a physical-chemical alteration of environmental medium due to diffuse sources and not linked directly to known and unique sources". However, nor the National legislation nor the contents of the Regional plans provide useful methodologies to quantify the phenomenon, making impossible to distinguish the PS and diffuse pollution existing in urban areas. Moreover, also in scientific literature there are few examples, mostly developed for the assessment of diffuse pollution spread in its classical sense, which is linked to anthropogenic practices carried out over large areas, such as agricultural ones. Unlike, in the case of urban areas it is not determined diffuse pollution from substances used in large scale in the area (e.g. Fertilizers, herbicides), but rather of a pollution caused by multiple sources, too small to be precisely identified and removed.

The aim of this work is to give a contribution to find a methodology in order to

- Distinguish PS (hotspot) and MPS (diffuse) contamination in urban groundwater.
- Estimate the concentration of diffuse contamination for those areas mainly connected with a diffuse contamination.
- Identify the urban areas which have the higher probability to be linked to MPS contributing to diffuse pollution.
- Identify a methodology to define a probability of each domain sector to contribute to the contaminant mass inflow with numerical code for transport model (MODFLOW+MT3DMS).

The proposed methodology, in a partnership with ARPA-Lombardy Region, was applied to Functional Urban Area of Milan (the city of Milan and some neighboring municipalities such as Monza and Sesto San Giovanni) which cover about 1120 km2. The study focused on Tetrachloroethylene (PCE) diffuse pollution assessment as it represents the main contaminant among the chlorinated solvents detected in the area. Many hydro-chemical data are available since Seventies and they can be updated with the most recent public databases (integrated with more recent

dataset ARPA, Metropolitana Milanese). The total database is composed by more than 44000 data monitored in 3458 wells/ piezometers and it is useful to reconstruct the PS history during last 50 years.

The applied methodology coupled both deterministic modeling of existing contamination (PS), in order to define the zones interested by the presence of a plume and stochastic modeling (MPS) in order to simulate the diffuse contamination, with statistical methods, in order to define the groundwater quality in the Functional Urban Area (FUA). Statistical procedure, such as Principal Component, Factor Analysis and Cluster Analysis, was applied in order to evaluate the magnitude of diffuse pollution. Five clusters above 15 can be considered representative of diffuse contamination, because the values are lower than the average of total analyzed sample. The deterministic transport modeling allowed the extension identification of plume related to PS or directly linked to the monitored concentrations. The modeled plumes showed the influence downgradient the PS and in particular, in Milan, the influence on the Water Supply Wells of the drinking water. Once modeled the plume, from the

chemical dataset were excluded those points affected by the plume and whose quality was obviously not determined by widespread pollution, but from a PS contamination. Data included into the new dataset were interpolated through geostatistical methods (ordinary kriging) applied to median concentration values in the period 2010-2014. PCE isocones maps identified areas where: 1) diffuse concentrations exceed the contaminated site threshold value (1.1 mg/l, Italian Law 152/06) but are lower than the drinking water threshold value (10 mg/l, Law 31/2001); 2) values exceed the drinking water limit. Maps are suitable to identify areas with different degree of diffuse pollution.

Combining maps with multivariate statistical results, referring to the two critical diffuse pollution areas mentioned above (>1.1 mg/l and > 10 mg/l), the summary statistics of the dominant cluster (Approach B1) or the average weighted on cluster frequency of the summary statistics (Approach B2) can be assumed as reference values for diffuse contamination. In conclusion, the highest PCE diffuse contamination in Milan was estimated to range respectively between 8 and 12 mg/l, whereas in the hinterland ranges respectively between 3 and 6 mg/l.

allows to consider the uncertainties linked to the diffuse contamination sources (MPS) in groundwater with a Monte Carlo procedure. Several calibrated models was generated considering the effect of some parameters (hydraulic conductivity heterogeneity K and contaminant inflow, with varying concentrations, to every cell of the top Laver model) governing groundwater flow and transport. In conclusion, the study gives to Public Authorities (Lombardy Region) useful tools to define diffuse PCE contamination. Using statistical and numerical model, the methodology could be considered a valid support to evaluate diffuse contamination reference values in the different sector of the Milan FUA. Otherwise, considering uncertainties due to MPS and environmental heterogeneity, a stochastic procedure, with a Monte Carlo procedure, offers some interesting solutions to point out areas where MPS are located and areas where higher mass releases contribute to diffuse contamination.

Furthermore, due to the

uncertainty related to the exact

position and intensity of MPS,

a numerical stochastic model

implemented in a pilot area in the

North-Eastern sector of the Milan

FUA. The proposed methodology

(MODFLOW/MT3DMS) was

STATISTICAL ANALYSIS OF PRECIPITATION, AEROSOL AND THEIR INTERACTIONS FROM A PARTICLE SIZE SCALE

Cugerone Katia - Supervisor: Prof. Carlo De Michele

Over the last decades, the importance of studying the structure of precipitation at particle size scale has been increasingly recognised, given its influence in a wide range of atmospheric and land processes. Applications in cloud physics and radar hydrology, calibration of space-borne and ground-based microwave precipitatio n sensors, soil science and agriculture are some of the environmental fields related to the raindrops size distribution (DSD). Precipitation is a non-stationary process, characterized by a great space and temporal variability mostly due to changes in atmospheric dynamics and cloud microphysical processes. These in turn are strictly connected with the properties and the distribution of the atmospheric aerosol particles, which are the preferential sites of droplet formation in the high atmosphere, influencing both cloud radiative properties and

precipitation's initiation. High suspended aerosol concentration in low atmosphere, usually due to large anthropogenic emissions, causes instead short-term health effects and increases the possibility of contracting serious chronic respiratory and cardiovascular diseases. Under these circumstances, precipitation influences the aerosol concentration, by scavenging the aerosol particles to the ground and cleaning the atmosphere. This research project explore the use of some statistical methods to study the variation of precipitation and aerosol from a particle size scale and their mutual interactions. In the first part of the research the focus is on precipitation. In particular, the issue of the absence of a unique general model able to describe the drop diameter variability has been addressed and the Johnson SB (JSB) distribution, has been firstly proposed for this aim. The validity

of this model has been deeply tested from a statistical point of view - large space has been given to the analysis of the Skewness-Kurtosis plane. Furthermore, the JSB capabilities in reproducing rain variables have been verified in order to prove its utility in practical applications. The second part of the research concerns the analysis of aerosols

and aerosol-precipitation interactions. Specifically, the aerosol particle number size distribution (PNSD) has been analysed in order to test the possibility of formulating a generalized model to represent the PNSD pattern. Then, the influence of precipitation on aerosol concentration in low atmosphere has been studied and the entity of the scavenging process has been computed and compared with literature studies. In both the two analyses, anthropogenic aerosol emissions have greatly influenced the final results.

Da Ronco Pierfrancesco - Supervisor: Prof. Carlo De Michele

Snow cover distribution is ruled by the effects of topography and atmospheric forcings. Complex mountain topography makes snow distribution variable over short distances and the spatial resolution of observations plays a key role in understanding its dynamics. Among Earth Observation data, the MODIS (MODerate resolution Imaging Spectroradiometer on board Terra and Aqua satellites) Snow Covered Area product proved to be appropriate for hydrologic applications due to its high spatial (500 m) and temporal (1 day) resolution. We consider ten years (2003-2012) of MODIS snow cover maps of the Po river basin, northern Italy. We investigate the issue of cloud obstruction,

highlighting its dependence on altitude and season. In spring, the percentage area hidden by clouds is about 70% above 1000 m a.s.l. We propose a cloud removal procedure and we apply it to the study area, characterized by high geomorphological heterogeneity. The regional snow line is estimated for detecting snow cover dependence on elevation and temporal filters aim to map snow cover in the transition altitudes. The cloud-reduced and cloud-free MODIS maps are used as reference for assessing snow cover simulations by the Regional Climate Model (RCM) COSMO-CLM, run at 0.0715° (about 8 km) and 0.125° (about 14 km) resolution. The RCM is able to reproduce the inter-annual variability of the

seasonal patterns of snow cover. Advantages are provided by the higher spatial resolution, reflecting the improvements obtained in temperature and precipitation fields. Finally, we discuss the feasibility of using MODIS data for investigating the signature of slope and aspect on snow dynamics in Central Apennines, Italy. The analyses highlight the importance of orographic effects resulting from topographic barriers to moist air circulation. In spring, the effect of solar radiation results in shorter snow cover duration on southfacing slopes. The results are supported by the assessment of the snow cover maps with respect to ground data (overall agreement of 86% for Agua and 88% for Terra MODIS).

ALPINE ANOMALOUS FANS: FROM THE GENESIS TO THE PRESENT INSTABILITY

De Finis Erika - Supervisor: Prof. Laura Scesi

Keyword: alluvial fans, anomalous fans, rock avalanche, debris flow, entrainment, RAMMS. The assessment of the hydrogeological hazard on some Alpine valley floors (i.e. Valtellina, Val Venosta) cannot disregard the processes ruling the evolution of the sedimentary fans. In particular, this thesis studied the typical processes linked to the anomalous fans, which are characterized by a very high ratio between the fan area and the area of the basin. With reference to these anomalous basin-fan systems and according to previous studies, the present work proposes an emplacement sequence reconstructed based on geomorphological, structural and stratigraphic evidences related to three Valtellina's anomalous fans, namely Migiondo, Ponte in Valtellina and Sernio fans (Sondrio, Norther Italy). These morphologies are classified therefore as fans dominated by landslide and differentiated from classical alluvial fans or debris-flow. The in situ surveys conducted along the Sernio Basin-fan system showed that the rock masses are characterized by a high degree of both fracturing and alteration. Sclerometric tests also pointed out a very high ratio between uniaxial compressive strength perpendicular to the schistosity and apparent compressive

strength which indicates the considerable alteration of the outcropping rock masses, as confirmed by the geological strenght index classification. The geomorphological survey showed evidences typical of Deep-Seated Gravitational Slope Deformation (DSGSD) along the head of the basin: double crests. trenches, counterslopes and lowered blocks are widespread elements. Furthermore, there is a series of main terraces. dislocated in smaller terraces. The area surrounding the basin shows scarp retreat tendency, and high detrition that created the conditions for the occurrence of several debris flow events. The distal part of the Sernio fan presents a deep (up to 80 m depth) and extensive (3.6 km) scarp, particularly affected by slope instabilities. Besides the analysis of DTM pointed out that the genesis of the most superficial and distal zone of the fan is mainly due to the repeated events of debris flow. Every new debris flow formed new deposits and has also partly eroded and demolished former deposits.

The main geomorphologicalsedimentological characteristics of the Alpine anomalous fans dominated by landslide can be summarized in the following points: 1) the total absence of, or very scarce flow of, the stream; 2) slopes >15% (Ponte in Valltellina 16.7%, Sernio-Lovero 19.8%, Migiondo 15.83%); 3) an extensive and imposing scarp of landslide surrounding the whole, or at least the half of, the same basin; 4) the apex that is often situated inside the valley; 5) a smooth surface of the fan; 6) steep and high slope eroded at the foot by the stream of the valley in the distal zone (e.g. Migiondo steep slope exceding 80 m high).

The basins which subtend fans dominated by landslide are often in areas of deep-seated gravitational slope deformations, greatly characterized by structural features even of regional interest (e.g. the basins of Sernio and Ponte in Valtellina are crossed by the Mortirolo fault and the Periadriatic Seam) and present mylonites. This study pointed out that the

genesis of these anomalous fans is related to the collapse of a sector of a DSGSD by rock avalanche, whose runout is confined; currently the proto-deposit is completely or partially hidden by more recent deposits of debris flows.

The identification of some sedimentary fan as a rock avalanche deposits raises several important issues for future hazard analysis and suggests that massive landslides may be more common than previously thought in Alpine area. Further studies of other deposits are necessary in order to understand how frequently such events occur in this region, especially for the areas close to main faults.

According to observed sedimentological evidences on the valley floor sediments, the emplacement of the fan caused the river diversion or the formation of a dam lake. The process of silting concerning the landslide dams has contributed to construct, inside the same valley, one or a series of morphological steps, that can be different even for a hundred metres in height The subsequent partial collapse of the dam, due to fluvial erosion, cuts the distal portion of the cone, creating a gorge more than 100 meters high. Stratigraphic evidences of the presence of ancient lakes were detected in tree cases on the Valtellina floor. The study of the drillings data affecting the Alpine valley floor of Valtellina for approximately 50 km, allowed this research to reconstruct part of the geological setting of the Quaternary Sequence in the area located between the fans of Ponte in Valtellina and Migiondo. The average depth of the boreholes and the water wells is approximately 30 m. Cyclic sequences have been observed, which allow to reconstruct events of damming that repeat themselves at times along the same part of the valleys floor in Valtellina, in correspondence with the present fans dominated by landslide (Ponte in Valtellina,

Sernio and Migiondo). Anomalous fans are often characterized by a high detrition rate on the basin and the main hvdrogeological hazard in these basin-fan systems is related to the occurrence of debris flows, favored by the following conditions: small basin with large amount of debris, high slope both in the basin and in the fan area, lack of an organized hydraulic network. The first two conditions also rule the runout process of debris flows in anomalous systems, bringing about a predominance of the erosion and entrainment processes in determining the magnitude of the event. In this study the model RAMMS DEBRIS FLOW (a numerical code describing the runout of a debris flow as a continuum based on the Voellmy-Salm rheology) was used to verify its applicability for debris run out assessment in anomalous systems. A back analysis was carried out to reproduce the debris flow dynamic in the Gadria (Val Venosta, northern Italy) anomalous system, where the fan area is often interested by the runout of debris flows. The source areas of these debris flows (located in the head zone of the basin) are guite small, whereas their magnitude (in term of volume of debris) on the fan are much higher, because of entrainment process. Actually, monitoring data showed that the volume eroded during the runout of the 2013 event is over the 80% of the whole final volume of the debris flow, stressing out that the effect of entrainment is one of the main factors to control the magnitude of the event, and

it must to be kept in account in

debris flows simulation. Based on the monitoring data available, the back analysis confirmed the capability of the software to reproduce the debris flow behavior and provided values of debris flow strength parameters. The comparison of the results with the available bibliographic data, indicate that the obtained parameters are more similar to the ones typical for rock avalanches instead of debris flows. The strength parameters obtained by the Gadria back analysis have been used as starting point for the numerical simulation of debris flow events in a similar anomalous system (Sernio, northern Italy (SO)) in order to define the fan susceptibility to debris flow. As no

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monitoring data were available for site-specific calibration, the simulation was carried out with a stochastic approach, considering a probability distribution of the friction parameters centered on the Gadria best values, and analysing the results in terms of probability distribution of the runout susceptibility and flow height. Numerical results pointed out the influence of entrainment in the hydrogeological hazard, especially with reference to the runout distance and the extension of the depositional area, which reaches the urban area on the fan. 260

CONSTANT AND VARIABLE DENSITY FLOW IN POROUS MEDIA, UNDER MULTIPLE SOURCES OF UNCERTAINTY

Dell'Oca Aronne - Supervisor: Prof. Monica Riva

In this thesis, we analyze flow and transport phenomena in porous media, under both constant and variable density conditions. In the context of constant density problem, we focus on flow and transport scenarios characterized by a level of heterogeneity in the porous media conductivity ranging from middle to high. Solution of the flow and transport problems are obtained by means of numerical simulations. In particular, to solve the transport problem we employ an anisotropic space-time adaptive discretization technique guided by *a posteriori* recovery error estimator. We investigate two different strategies to guide the adaptivity, one merely based on the features of the resulting concentration field and a second that entails both concentration and velocity fields. We found a satisfactory comparison between results grounded on the use of both adaptive discretization and results for fixed uniform discretization, which level of refinement is established through a convergence study.

In the context of variable density flow within heterogeneous porous media, we analyze the reduction, respect to the constant density case, of the solute dispersion when two fluid of different density are mixed under stable condition. To highlight the interaction between the heterogeneous permeability of the porous media and the buoyant stabilizing effects, induced by the flow and transport coupling, we introduce a new decomposition of the velocity field. The variable density velocity field is view as the sum of a stationary components. associated with the solution of the flow problem for constant density. plus a dynamic components, related with the coupling effects. The proposed decomposition allow to identify and quantify the origin of the solute spread reduction. In essence, the stabilizing effects identify with the dynamic components leads to a regularization of the stationary velocity field at the solute front. This regularization of the velocity field is at the origin of the manifested solute dispersion reduction. Moreover, we derive an effective model satisfied by the ensemble average of the horizontal average of the concentration. The spatial averaging (upscaling) operation lead to the introduction of a dispersive flux in the effective model, allowing to retain the effects of the unresolved details of the permeability in terms effective prediction. Ensemble average is introduce to deal with our limited knowledge of the porous media properties organization. For the

proposed model, we provide both semi-analytical results and Monte Carlo based solution, which compare well. For the environmental issue of saltwater intrusion along coastal

aguifer we perform a Global Sensitivity Analysis for global descriptors of the intruding wedge with respect to typically unknown flow condition and porous media properties. In particular, we rely on variance-based Sobol' indices to quantify the sensitivity. Due to the high computational costs associated with the numerical solution of the coupled flow and transport problems that govern the saltwater intrusion dynamics we introduce a generalized Polynomial Chaos Expansion of the global descriptors of interest. The gPCE allow for a direct evaluation of the Sobol' indices and permit to obtain probability density function of the output at affordable computational costs. This task is computationally prohibitive relying on the full numerical model. As conceptualization of seawater intrusion we take the anisotropic dispersive Henry problem. Results shows that the dispersive properties of the media greatly affects the mixing between salt and fresh waters, the intensity of the buoyancy effects determine the inland intrusion of the wedge and the anisotropy ratio of the

media permeability dictates the variability of the vertical height of the wedge along the coast. The same kind of Global Sensitivity Analysis is applied in the context of hydraulic fracturing operation, with the aim of define the sensitivity of the global level of contamination in a vulnerable aquifer in communication with the aquifer of production respect to input model parameters. For the test case here analyzed, results shows a great level of sensitivity of the level of contamination to the aperture of the fracture and the pressure of injection of the fracturing fluid. These two applications demonstrate the benefits carried by a Global Sensitivity Analysis

in terms of understanding of the system behavior and proper quantification of the sensitivity. In the end, we propose a new Global Sensitivity Analysis grounded on the first four statistical moments of the model output probability density function. We define the sensitivity of an output respect to an input on the base of new metrics entailing the mean, variance, skewness and kurtosis of the output. Our methodology provides a comprehensive characterization of the output sensitivity. Results shows that the output sensitivity to input parameters is a function of the particular statistical moment analyzed. The application of our

approach can be of interest in the context of current practices like factor fixing procedures, design of experiment, uncertainty quantification and environmental risk assessment, due to the role of the key role of the first four statistical moments of a model output in such analyses. We demonstrate our methodology for an analytic test function widely used as benchmark for GSA studies, in the context of variable density scenario for the critical pumping rate in coastal aquifer and regarding constant density problems, we focus on the breakthrough curve of a tracer solute at the outlet of a heterogeneous sand box.

FLOOD IMPACTS ON AGRICULTURE RISK ASSESSMENT

Fakhruddin Shamsul Hassan M. - Supervisor: Prof. Scira Menoni

The Thailand floods during the 2011 monsoon season are known to be the worst flooding on record in terms of both the volume of water and the number of people affected. Large parts of the country were submerged in the upper northeaster part down to the central part of Thailand and impacted agriculture, economics and life in general to a great extent. Despite the gravity of flood damage and the importance of the agricultural sector, the process of assessing damages is limited. This study covers a broad scope of topics to bring together several factors that intersect floods and agricultural damage assessment. The research included flood modeling due to future climate change, agricultural

damage assessment for present and future, and the quantification and effective communication of probabilistic information. The overall methodology are shown in the **Figure 1**.

As shown in Equation 1-1, this study adopted a simple, additive weight-based approach to indicator aggregation that is quick and widely used. Aggregation gathers together all of the information used in the model to form of an indicator and to portray an overall picture of agricultural sector vulnerability. This approach is widely used in vulnerability studies cited in literature (Fakhruddin et al. 2015: Moss 2001; Ebert and Welsch 2004; Gbetibouo et al. 2010; Babel et al. 2011; Preston B.L et al. 2008).



where V = agricultural flood vulnerability n = number of vulnerability indicators W_i = weighting coefficient for indicator I

 $I_i N$ = the normalized indicator

Normalization is required to bring different types of indicator data into a common platform where they can be aggregated. For each subset of the vulnerability model, Equation 1-2 indicates the approach used for normalization.

 $\boldsymbol{I}_{iN} = \frac{\left(\boldsymbol{I}_{i} - \boldsymbol{I}_{imin}\right)}{\left(\boldsymbol{I}_{imax} - \boldsymbol{I}_{imin}\right)} \qquad (1-2)$

where



1. Overall methodology and study area

I_i = the average value for the ith indicator I_{imin, max} = the minimum and maximum of the average value for indicators i through n

The 1D/2D flood model has been simulated for the Upper Chao Phraya River Basin for 2011 flood and future scenario based on CMIP5 data (fifth phase of the Coupled Model Inter comparison Project).

This study produced a comprehensive quantitative and qualitative results on agriculture damages for flood hazard. Rice was the main crop selected because of its high land occupation in the area of interest. Four different scenarios were considered for loss calculations which are climate in 2020 and the flood probability of occurrence (AEP) at 0.5%, 1% and 2%. The 2011 flood event in Thailand was used as a reference to see the difference between each scenario. Vulnerability and losses were calculated for mature and maximum tillering rice stage



2. Agricultural damage due to flood

growth at different level of water depth form 1m to 4m and time of submergence. For a flood duration condition of one day with a given water level of 1 to 4 m, the loss in rice production was estimated at 9 Million USD in 2011, 11 Million for AEP 0.5%, 12 Million for AEP 1% and 13 Million for AEP 2% and 15 Million USD for the climate 2020 (Figure 2). Result showed that climate change influences the most in rice field loss due to flooding and can affect both the guality and the guantity of the production. It also shown that mature rice is more vulnerable

than maximum tillering rice stage under flooding (Figure 3). We developed a hybrid framework for flood loss and damage uncertainty analysis and involvement of end users through questioner survey and focus group discussion. The findings demonstrated uncertainty framework developed could be used to identify areas within the data management and transformation process that could benefit from further improvements. Based on these results, certain recommendations are highlighted.



3. Mature rice submergence damage (left) and maximum tillering rice submergence damages due to climate change

Feki Mouna - Supervisor: Prof. Marco Mancini

Co-supervisor: Dr. Giovanni Ravazzani

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This research work included both field and laboratory experiments together with modeling activities. The main aim of this thesis was to improve soil moisture simulations based on the improvement of the model structure and parameterization. The model was used as a tool to assess the efficiency of irrigation management in two surface irrigated maize fields. The first part this thesis was dedicated to the improvement of soil moisture simulations through the implementation of different equations of infiltration. VADOSONE PROGRAM was developed within which: Philip's equation, modified SCS-CN method, Green Ampt method and Ross 2003 model as a numerical solution of Richards equation, were implemented. These methods aim at quantifying the infiltration in the vadose zone. Ross 2003 model, a non-iterative fast solution for Richards equation, was modified and included within the subset of infiltration module. The developed VADOSONE PROGRAM was included in a further step within FEST-WB distributed hydrological model. Within Ross 2003 model different soil water retention curve models were implemented Brooks and Corey, Van Genuchten-Mualem

and modified Van Genuchten. Sensitivity analysis of input parameters of these equations was carried out in order to understand which are the most important parameters for model calibration. The calibration and validation of soil moisture simulations based on the different implemented infiltration models were carried out for Livraga's study site. Results showed that all tested methods when properly calibrated gave quite similar performances and sufficient accuracy. The advantage of ROSS solution is that it allows following the variation of soil moisture along the soil profile that was not possible with the other analytical methods. From these analyses we concluded that soil hydraulic parameters and in particular the saturated hydraulic conductivity have a great importance for the accuracy of the results of soil moisture simulations. We decided to investigate more deeply the accuracy of implemented parameter retrieval methods. Adding to that, when we carried out the calibration of the VADOSONE PROGRAM for 2012 cropping season, we found that achieving a good calibration with the same set of soil hydraulic parameters during the entire cropping cycle was

not possible since a part of the simulation period was under or overestimated that is due probably to the temporal dynamic of these parameters. In order to confirm or deny this hypothesis, we decided to assess these parameters temporal as well as spatial variability during a cropping cycle. Noting that only few studies have addressed this variability. The second part was about testing different methods of soil hydraulic properties measurements and estimations, as well as assessing their spatial and temporal variability due to a possible effect of the crop growth or agricultural practices on these properties. For the determination of the saturated hydraulic conductivity parameter, several field campaigns within which field measurements were performed using double ring infiltrometer and Guelph permeameter, also intact and disturbed soil samples were collected in order to measure the bulk density, organic matter content and particle size distribution. Laboratory measurements of saturated hydraulic conductivity were carried out using KSAT-UMS device following falling and constant head methods. We compared different methods for the KSAT determination

using in-situ and laboratory measurements (falling head and evaporation method) and assessed the applicability of HYPRES and ROSETTA pedotransfer functions (PTFs) for the KSAT estimation. The results showed that the Guelph permeameter underestimated the KSAT in comparison to the double ring and falling head measurements. The tested PTFs showed guite similar performances while their easiness and convenient use make them potential alternative techniques for the KSAT estimation in comparison to on-field and laboratory measurements. The KSAT is sensitive to the selected determination method that yielded different results when implemented as input for hydrological model simulations. The evaporation method experiments using HYPROP-UMS device were performed for each soil sample. Fitting procedure of the results of these experiments was carried out following Brooks and Corey (BC) and Van Genuchten (VG) models. Several PTFs were tested: seven of them that fit the BC and four for VG using CalcPTF. Results of these tested PTFs were compared to evaporation method results. Together with these tested regressional PTFs, ROSETTA that is based on ANN (artificial neural network) was also used to predict soil parameters. A multimodal approach was applied based on simple averaging of outputs of simulations based on both direct and indirect determined soil water retention and conductivity curves allowed an improvement of soil moisture simulations results.

The third step was dedicated to assess the temporal and spatial variability of soil hydraulic properties over a cropping cycle and to quantify their effect on soil water movement simulations. Monitoring of soil properties was carried out during three measuring campaigns during a cropping cycle for a Maize field located in Secugnago. Results of this study showed that soil surface is subjected to temporal variation during the cropping cycle due to: drying/wetting cycles, fertilization, roots development, irrigation, tillage and harvest. The saturated hydraulic conductivity was a sensitive parameter to temporal changes. This parameter is required as input for many ecological, environmental and agricultural models, so this variation should be taken into consideration. At farm scale, the comparison of spatial and temporal variations of measured soil properties showed that temporal changes are much important. Results illustrated the importance of considering time and spatial variability of soil properties while modeling soil water movement. Considering these parameters as static in time yielded inaccurate results. Though soil hydraulic properties estimation is expensive and time consuming, better understanding of these parameters dynamics during cropping cycles would improve soil moisture predictions especially for precision agriculture applications. The last part was devoted to the use of VADOSONE-PROGRAM and FEST-WB as tools to assess the

efficiency of previous irrigation

practices through a calculated stress index. Simulations were performed for Livraga's study site for previous cropping season of 2012 and Secugnago site for the year of 2015. For the second study site we considered stress threshold and surplus threshold as variable in time since the temporal variability of soil properties has been proved previously. It has been proven that depending on the selected infiltration model and if the temporal variation of stress and surplus thresholds were taken into consideration or neglected impacted the evaluation results. The implementation of Ross model as a numerical solution of Richards equation allowed us to get an idea about the water status within the soil profile. The numerical solutions of Richards equation are not usually used within decision tools due to their limitations (Time consuming and mainly presenting convergence problems). Implanted within the VADOSONE PROGRAM, Ross solution allowed us to assess water stress conditions at different depths. Such an evaluation is important if the simulations of soil moisture are implemented for precision agriculture practices. The developed VADOSONE-PROGRAM can be implemented also a decision support tool for irrigation scheduling for future projects. The spatial variability of soil moisture and stress index was assessed through FEST-WB simulations. Results proved that the use of distributed models provided more information about the spatial variability of water depletion and stress in the field thus the use of local simulations can lead to inadequate decisions.

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Gottardi Caterina - Supervisor: Prof. Francesco Guerra

Co-Supervisor: Prof. Evangelos Livieratos

Based on the experiences accumulated at the luav University of Venice, the research developed during the three years of the PhD course has focused on the study and application of analytical methods for the valorisation and actualization of historical cartography.

Unfortunately, not always the cartographical documents preserve their contents and physical shape during the years; for example, the humidity action could damage this highly valuable heritage. Occasionally, the metric content of maps is preserved in written historical documents, even though its graphical representation is no longer available: in these cases, it is possible to apply a numerical analysis in order to understand the missing graphical description, which initially represented an integral part of the oeuvre.

This project aimed at defining a methodology procedure for the study of historical cartography, modifying the investigation techniques according to the type of analysed data, which could be either a graphical representation or simply numerical information. The study has especially focused on two main different areas: a numerical and comparative study of the Liber de Existencia Riveriarum et Forma Maris Nostri Mediterranei

and an analytical study of the oval projections of the 16th Century based on strain analysis. This approach has been used in order to define a methodology for both the study of a historical document dated between 1160 and 1200 AD and for the analysis of cartographic documentation dating to the 16th Century. Initial data are therefore different: for the first case, distances and directions relating to the descriptive text of an unknown Pisan author have been analysed; in the second case, metrical analysis have been directly produced on the cartographical representation of Renaissance maps.

The cornerstone of the dissertation is certainly the numerical analysis of the *Liber* which is given by the

originality of the studied theme and the complexity of the analysed data. In this case, working with heterogeneous data originating from different sources and epochs required an information management tool with the ability to relate data together. Since the beginning of the research a GIS system has been employed in order to manage and analyse metrical and geographical data in their historic-temporal evolution. The *Liber* should not be interpreted just as a real portolan, it is not a mere enumeration of names and harbours with relevant measures, but it contains many other descriptive information, for example of inland cities. It also presents a list of distances between



1. A representation of some of the analysed Liber's distances.

harbours across the Mediterranean Sea that do not follow the costal path, which we have called **traverse**. The work started from the study of *Liber's* toponyms in relation to current cartography; once the localization for the historical toponyms has been determined, the following phase involved data acquisition and gathering of the *traverse'*s measures for three different cases: for the *Liber*, for today and for Ptolemy's Geography. We have attempted to define a general descriptive model able to distinguish between different factors affecting the uncertainty of the analysed measures: in order to estimate the conversion ratio and the error, it has been applied a linear regression analysis on the datasets acquired.

We have also started to set up a comparative study between the Liber and Ptolemy's oeuvre, in order to identify a feasible method to study the origins of portolans and their existence before the Middle Ages; the correspondence between the Liber and Ptolemy proves very feeble, although this may be due to the preliminary stage of the study. The analysis may represent a potential direction for a future development: research areas are various and complex as the uncertainties on the information given by Ptolemy are high. The implemented GIS will allow scholars to visualize data in a spatial context and to share them between research groups. A prospective development will be data integration with other information, for instances portolans ensuing the *Liber*: this will promote a dialogue between different disciplines, fostering the development of historical

knowledge and the understanding of the cartographic evolution throughout history. Concerning the second case study it has been chosen to analyse a peculiar typology of cartographic representations: these are the oval projections used during the 16th Century for representing the known world. Six historical maps have been studied, which have been compiled by Contarini and Rosselli, Bordone, Agnese, Gastaldi, Ortelius and Ricci. In literature, we have the analytical statement of the **Agnese-Ortelius**

model, also including Gastaldi's and Ricci's. Functional to the present study, the grid has been

0,503 1,671 5,217 **0,244 0,625 1,189 1,717 1,9** 0,382 0,845 1,423 1,931 2,1 1,9 1,9 0,098 0,22 0,354 0,447 0,475 0,475 0,475 0,475 0,475 0,475 0,475 0,475 0,475 0,475 0,687 0 0,023 0,049 0,072 0,088 0,092

redrawn following formulas and maintaining the pace of historical maps. The analysis has focused on the known projective systems: in these cases, the strain parameters have been calculated in order to evaluate the metric properties and the projection's deformations. The strain analysis represents a method tested in past researches, attempting to offer an

alternative to Tissot's indicatrices calculations for the analysis of metrical deformations. In the case of Rosselli and Bordone, in the absence of analytical formulas to start with, grids have been redrawn starting from those represented in historical maps. The lack of explicit formulas did not allow calculating metric tensors and analysing deformations. A future research prospective could involve the development of a methodology to study unknown projections from the process of redrawing grids. In conclusion, innovative Geomatics tools enabled to study the oeuvre of *Liber* through a not yet experimented analysis, comparing



calculated dilatation Δ (bold) and maximum shear y (italics) distributions for the Ortelius's map.

Medieval and contemporary data and providing a starting point for future research on the potential origins of portolans. Moreover, by applying an innovative method, it has been possible to produce an in depth analysis on one typology of historical maps, opening future research perspectives in relation to the identification and study of unknown projections.

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VORTEX INDUCED VIBRATION ON OSCILLATING BODIES

Mandelli Simone - Supervisor: Prof. Stefano Malavasi

This thesis presents an experimental and numerical analysis of a fluid-structure interaction phenomenon: the vortex induced vibration on oscillating bluff bodies. A cylinder and a beam-supported sphere are considered, the first one is a rigid body with one degree of freedom while the second one is a rigid sphere attached to a deformable beam with two degree of freedom. This work proposes, initially, an experimental-numerical investigation of the main flow field characteristics and pressure field analysis around a freely oscillating rigid circular cylinder immersed in a high Reynolds number flow in the subcritical range. The cylinder is characterized by high value of mass ratio and mass damping, while the damping itself is guite low. Here the numerical results are compared with experimental data obtained in the Politecnico di Milano wind tunnel under the same fluid dynamic and mechanical conditions. Unsteady RANS analyses on a rigid body with one degree of freedom are performed. The preliminary check of this numerical setup is provided by considering the case of a fixed cylinder in the subcritical region. Based on this benchmark, the full setup is checked by considering fluid dynamic conditions outside the lock-in region. Finally, a

number of points are investigated on the cylinder's steady state response curve in the lock-in region. The numerical model yields good results in terms of cylinder amplitude response, aerodynamic forces and pressure field analysis, in agreement with the results of the experiment. The numerical model was able to reproduce displacement, and the relative phase between lift force and oscillation is correctly provided. Moreover, phase averaged pressure distribution was computed and compared

with previous experimental measurement. Finally, numerical vorticity fields are investigated. Result strengthens the experimental observations reported in previous works and in literature which assert the presence the extension of the 2S vortex shedding mode area. Furthermore, in the transition to the upper branch the 2P0 mode was detected and the presence of the 2P mode was confirmed at maximum oscillation amplitude. Analysis of the numerical reconstruction of the flow field



1. Numerical (red) and experimental (blue) pressure distribution of an oscillating cylinder along an oscillation cycle



2. Numerical and experimental benchmark of free oscillation in steady water of the beam supported sphere

evolution is therefore considered to yield further information on the vortex shedding mode, especially in the transition region between 2S and 2P mode. Thus, starting from the previous model we performed numerical analysis of Fluid-Structure Interaction of a submerged beam-supported sphere through the Co-Simulation technique. Co-Simulation revealed itself as a powerful and useful solution for the simulation of such fully coupled problems. A two degree of freedom system involving a deformable structure is considered. Coupled phenomena require co-simulation technique in which CFD software is coupled with a structural one in order to simulate complex FSI phenomena with a partitioned approach. The beam supported sphere deals with the application of the Co-Simulation technique to the case of the vortexinduced vibrations (VIV) of a beam supported sphere in a free surface flow, experimentally investigated. Two standalone models for the fluid domain and the structure are calibrated separately; then

we arranged the co-simulation of the free decay oscillations of the system in still water and in uniform flow. This simple benchmark case was useful in order to explore and adjust the specific coupling settings of this kind of analyses and, in the end, we were able to satisfactorily reproduce experimental data of channel flow test of the oscillations in still water. Nonetheless, several difficulties may arise in the choice of the partitioning scheme and of the algorithmic details for the step-by-step time integration. This problem seems guite absent from literature so far. In this thesis, the computational issues are thoroughly investigated and the model is validated by comparison with the experimental data. The system is analyzed in still water to set-up and validates the model. Then the vortex induced vibration of an oscillating sphere at guite high Reynolds number was proposed. The model was validated through a benchmark with the experimental analysis. Cross-flow displacement and the corresponding frequencies had a good agreement with the

experimental data. However the model was not able to reproduce the streamwise displacement and as a consequence the proper dynamic of the fluid structure interaction. Further analyses from the fluid dynamic point of view are required.

In the end, a possible application for energy harnessing purpose is proposed. Exploiting the transverse movement of the sphere with a linear generator inside the



3. Beam supported sphere with the internal linear generator

sphere itself is possible to harness energy. A scale-lab model is designed to maximize the power output of the generator used and experimental tests are performed to measure the dynamic behavior and the output power of the linear generator. Experimental tests were performed in hydraulic channel using a geophone as linear generator. The beam supported sphere was designed to maximize the harnessed flow energy and measurements of displacement and power take off were performed. The results showed the applicability of the system to a full scale model.

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GEOREFERENCING, ANALYSIS AND MANAGEMENT OF DATA FROM ARCHIVAL DOCUMENTS: GIS TECHNOLOGIES AND GEOSERVICES FOR HISTORICAL CARTOGRAPHY

Minini Guido - Supervisor: Dr. Daniela Carrion

The aim of this work of thesis is to analyze in detail all the phases of planning that led to the implementation of a geodata service for historical research, comparing developed or assumed solutions and justifying the design choices made. The research raised from an Italian Research Project of National Interest (PRIN - Progetto di Ricerca di Interesse Nazionale) related to the application of GIS technologies to medieval data stored in historical sources. Historical sources taken into account are tax-related registers, dating back to the fifteenth century; they refer to the Kingdom of Naples lands, corresponding to the southern part of Italy. They provide interesting information on the social and economic dynamics

that developed in that historical period. The archiving of data obtained from sources was carried out on a relational database structure, which is the most widely used model to manage complex data systems in information technology. The design of the relational schema took place in collaboration with a research group of historical medievalists: they represent the end users of the geodata service, so they have to provide recommendations on characteristics and features requested to the service. The support from medievalists is also required for the georeferencing of place names listed in the historical sources. Point geometries resulting from this activity are managed at database level by the

DBMS PostgreSQL; its PostGIS spatial extension enables Web publishing of spatial data within a geodata service. The Web solution tested as part of this thesis project consists of a geoportal prototype, created with the GeoNode platform. The geoportal allows to explore and to make spatial gueries on the historical data (map service) and to consult metadata (catalog service). This solution is compared with a prototype of WebGIS, made a few years earlier in the context of another Ph.D. thesis and designed to host the same historical data, and with other possible solutions for publishing a geodata service, in order to identify the critical issues that emerged in comparison with requirements, and to solve them.

LOW COST GNSS RECEIVERS: NAVIGATION AND MONITORING ACTIVITIES

Negretti Marco - Supervisor: Prof. Ludovico Biagi

In this PhD research different conditions of using of low cost GNSS receivers were explored in **navigation** and **monitoring activities**. These receivers are cheap and widespread, but they are single-frequency receivers and then less accurate than the geodetic dual frequency receivers. In navigation applications the single-frequency receivers are largely used and in most of application the accuracy of tens meters usually reached in point positioning is enough, but there

are some particular cases where it is needed to increase it: this is the case of the MEP (Map for Easy Path) project where the aim is to improve the urban mobility of the physically impaired people. One of the ways is an activity of mapping obstacles, done by volunteers with common mass market devices. Therefore the final accuracy should be improved and two different procedures were implemented and tested with the aim to correct positions estimated with these low cost receivers:

- · correction using data from Continuously Operating Reference Stations;
- · correction using local cartography as reference.

In **monitoring activities** the GNSS geodetic receivers are already used, but there are situations where these receivers are not

suitable, mainly due to the great economic effort that they require. The adoption of low cost GNSS receiver can expand the field of application of GNSS techniques, but their accuracy in positioning must be increased.

Navigation: correction using data from CORS

Let's consider the CORS optimally estimated position and the CORS positions estimated epoch by epoch: the first one is the actual position when the others are affected by the environmental effects presents at the epoch in which the survey was done. Therefore the difference between actual position and position at a generic epoch i it can be assumed due to specific errors present at this particular epoch. For correlated in space errors, if the rover is near the CORS, you can assume that these errors will be more or less the same that afflict estimations done with the GNSS low cost receiver. It is possible to compute the difference between actual and estimated CORS position and therefore to try to improve accuracy of rover positioning applying to the rover trajectory the corrections from CORS data, computed epoch by epoch.

In the correction procedure takes into account also of the different

satellites visibility between CORS and rover: rover usually is in a worse position than the CORS, so it can view only a subset of satellites viewed by CORS. Two different kind of test have been done: in ideal conditions, with a static occupation and in normal working conditions, with data collected during several repetition of two test paths, in an urban scenario.

In the first case, two test sites have been used: both with good satellites visibility for a total of 15 days of data from static observations. Observations were processed and corrected with data from two near CORS stations: the final results were improved by the correction, with most of statistical errors indexes improved, therefore the tested correction method in static survey worked.

In the second case test two test paths were defined and repeated several times collecting data using a geodetic receiver and some low cost receivers (single frequency). The data from the geodetic receiver were processed by a kinematic postprocessing and provided the benchmark epoch by epoch to evaluate the positioning accuracy of the low cost receivers tested.

Errors statistic were compute before and after applying

corrections from the CORS like did in the first case. Unlike what it was obtained with the data from static positioning, in this case the accuracy after the correction does not improve. This is probably the effect of local noise, due to particular properties of the area where the survey was made (like multipath), that obviously can not be removed using data from reference station, where this kind of noises are not present.

Navigation: correction using local cartography as reference

As reference map it was chosen OpenStreetMap (OSM), due to the several advantages offered: it is a collaborative project, the data access is free and permits to use, download and modify data freely, without particular restrictions, keeping them always up to date. Therefore it is possible get data and organize them in a local database (PostgreSQL and its extension PostGIS) with the data collected during the survey activities and so to use the database tools to match data and then to correct the positioning. Different policies were explored to implement the corrections:

- path segments as reference, in this case the only acceptable position for a collected point is assumed on a OSM path segment and all the points that are not on a OSM segment must be corrected.
- **building as exclusion**: in this method the point position will be classified as wrong only if the point is inside a building;
- buffer as reference: this method uses the path

segments like the first correction method viewed, but in this case the point position will be considered wrong only if the distance from a segment will be greater than a certain threshold.

The different correction procedures were compared checking how many points, after correction procedure, are near the actual path done, where the actual path is known and specifically defined for these tests. All the methods implemented improve the accuracy of points collected, but there is not a method that is always better to another one: the final results depend significantly on the conditions in which the survey was done, the site characteristic and from the cartography used as reference.

Local monitoring

The purpose of local monitoring is to model displacements, evolution and deformations of civil engineering structures and local phenomena such as landslides. This monitoring activity is very important to avoid damages and possible victims. Different techniques are possible to do local monitoring, between these, in the last fifty years, the use of GNSS receivers has had a great development that permits to reach accuracy less 1 cm, in case of dual frequency receivers. Nevertheless, the high cost of these receivers can represent a problem then it could be interesting verify if it is possible do local monitoring with GNSS techniques, but using low cost receivers. The accuracy obtained

with low cost receivers has not yet completely tested, so in this thesis it was verified:

- how reliable are the results obtained or rather, how many false or missed alarms are expected per unit of time (significance);
- the ability to identify at least the order of magnitude of a

displacement (congruence). The experiments were planned in order to assess the precision and the accuracy of low-cost GNSS receivers in monitoring dynamic displacements, with the aim of evaluating which is the precision level reachable, comparing scheduled displacements and detected displacements obtained using these kind of GNSS receivers.

The tests were done using tools to control the imposed displacements along horizontal and vertical direction. The obtained results shown how the general displacement trend is recognizable: along the horizontal direction the results are satisfactory, with the estimated points close to the imposed positions. Along the vertical direction the results are worse: the general trend is still recognizable, but the individual movements are almost impossible to identify, probably due to the high noise of the cheap antenna used. Therefore a low cost receiver can be used, under specific constraints, in survey activities. The vertical component is not well estimated, so the main displacement in the monitored area should be in the horizontal component to use efficiently the low-cost receiver.

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FUNCTIONAL SECTORIZATION AND OPTIMIZATION OF WATER DISTRIBUTION NETWORKS

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Sub-zoning, introduced in U.K. water industry in 80's, is now used worldwide to enhance the efficiency of water distribution networks (WDNs). Typical objectives of DMAs, such as supply costs and leakage minimization, water guality and efficiency maximization, are also produced by energy optimization. The present Ph.D. thesis focuses on district metered areas and energy optimisation techniques in the field of the efficient management of water distribution networks serving urban areas. The final objective is to develop new tools apt to deal with complex water distribution networks, highly looped and characterised by multiple water sources. In case WDNs supplied by multiple water sources (i.e. production stations) the effect of districts should be considered even more thoroughly than in case of single sources supply, for the difficulties to consider supply volume and flow distribution coming from the different sources.

To tackle these aspects, it is first introduced in this thesis the concept of "elementary areas". Each elementary area represents the inference zones in terms of water distribution of a given source of the network, thus they also represent the least possible subdivision of the network into

isolated self-sufficient districts. Firstly, using elementary areas, a novel method to automatically design DMAs is proposed, based graph theory. Elementary areas enlighten the subnetworks already present in the network and reflect the operation of the system. Then elementary areas are assembled each other to make larger DMAs. The union strategies can be the most different from the maximisation of network performance to keep unchanged the original interactions between the different sources.

Secondly, two alternative approaches to identify elementary areas are considered: one based on particle tracing and the other still based on graph theory, being a variant of the originally proposed method. However, for both alternative approaches resulted reasons not to prefer them over the originally proposed method, which proved more effective both in terms of consistence to the intended definition for elementary areas and for computational time. Thirdly, the application of elementary areas for optimal energy management is investigated. A novel optimization approach of pump schedules is proposed exploiting elementary areas as functional districts. Being

the inference zone in terms of water supply for water sources, each area can be energetically optimized in order to obtain a good solution to use for the entire network optimization. This approach, named "expeditious" method, is successfully applied on a complex case study (95 pumps). Finally, a serious comparison of methods is performed to solving the pump schedule optimization problem of large networks with an elevated number of pumps. The comparison involves, besides "expeditious" method, genetic algorithm and mixed integer linear programming. The final goal is to enlighten strength and weakness aspects of the algorithms tested: easiness of implementation, capacity to investigate large solution domains, computational time and robustness. A complex case study is used as test field.