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MODELIRANJE ONESNAŽEVANJA MEHIŠKIH LAGUN S POLJEDELSKIH POVRŠIN – PRVI DEL: METODOLOGIJA
MODELLING OF AGRICULTURAL POLLUTION IN MEXICAN LAGOONS – PART 1: METHODOLOGY

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V številnih mehiških obalnih lagunah gojijo ribe, škampe in školjke. Večinoma pa so v zaledju lagun poljedelska območja, s katerih z vodo odtekajo v lagune tudi hraniva in pesticidi, ki pogosto onesnažujejo morsko hrano nad dovoljeno mejo. Cilj raziskave je predlagati nekaj optimalnih načinov poljedelskega upravljanja, ki bo v zadostni meri zmanjšalo onesnaženje vode in morske hrane v lagunah. V prispevku opisujemo metodologijo reševanja problema s sistemom dveh numeričnih modelov. Z modelom GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) najprej za znane podatke o padavinah, tipu tal, tipu pridelka in vrsti hraniv in pesticidov določimo iztok vode, sedimentov, hraniv in pesticidov z območja. Potem z modelom PCFLOW2D izračunamo širjenje in koncentracije onesnaževalcev v lagunah. S pomočjo obeh modelov in z nekaj nujnimi meritvami bomo predlagali optimalni način poljedelskega upravljanja. Ta prispevek opisuje predlagano tehnologijo, v drugem delu bo podrobno opisano modeliranje cirkulacije in širjenja polutantov za sistem lagun ob dolini Carizo v SZ Mehiki, v tretjem delu pa bo opisana uporaba modela GLEAMS in predlagane končne rešitve.
Ključne besede: *dvodimenzijsko hidrodinamično modeliranje, modeliranje polutantov, model GLEAMS, obalne lagune, Mehika, marikultura*

Many coastal lagoons in Mexico are used for mariculture (fish, shrimps, oysters). Regions near lagoons are usually exploited by agriculture, and drain water from this area brings nutrients and pesticides into the lagoons, which can contaminate products of mariculture. The goal of the research is to propose some scenarios of "optimum" agricultural management, which will enable diminished contamination of the lagoon water and marine food. First, several possible scenarios of improved agricultural management are studied. For each scenario numerical simulations are carried out by two models. Simulations by the GLEAMS model (with input parameters of hydrology, soil type and applied nutrients and pesticides) gives information on the contaminant contents in the drain water from the fields. Further on, simulations by two-dimensional hydrodynamic and pollutant transport model PCFLOW2D shows the distribution of contaminant concentration in the lagoons. By means of both models and some measurements, an optimum scenario of agricultural management will be proposed. This paper describes the proposed methodology, the second part will describe in detail the hydrodynamic and pollutant transport simulations for the case study of the Carizo valley in NW Mexico, and the third part will deal with modelling of agricultural pollution by the GLEAMS model and proposed management for the same case study.
Key words: *twodimensional hydrodynamic modelling, modelling of pollutants, GLEAMS model, coastal lagoons, Mexico, mariculture*

1. OPIS PROBLEMA

V Mehiki je večje število sistemov lagun, kjer marikultura predstavlja pomembno gospodarsko panogo. Glavni produkti so ribe, školjke in škampi. Navadno pa se območja okrog lagun uporabljajo za poljedelstvo. Na območju mehiških držav Sonora in Sinaloa je več kot 1 250 000 ha poljedelskih površin, ki jih namakajo, vse pa ležijo v bližini 44 obalnih lagun, kjer imajo velik ulov rib.

Problem je v dejstvu, da za izboljšanje poljedelskih pridelkov uporabljajo gnojila in pesticide. Voda, s katero namakajo, pa spira te polutante v lagune, kjer pogosto onesnažujejo morsko hrano. V glavnem imajo hranila vedno škodljiv učinek na kakovost vode v lagunah, v večjih koncentracijah lahko povzročijo evtrofikacijo. Pesticidi pa so toksični in dopustne koncentracije v vodah, kjer se goji marikultura so vedno zelo majhne.

Glavni cilj raziskave je predlagati metodologijo, s pomočjo katere bi zmanjšali koncentracijo hraniv in pesticidov v lagunah tako, da bi ostala v sprejemljivih mejah. To bi dosegli z naslednjimi postopki.

Najprej je treba določiti možne postopke za zmanjšanje vnosa hraniv in posebno še pesticidov s polj v lagune. Mogočih je več ukrepov, predvsem v obliki izboljšanega poljedelskega upravljanja. V ta namen uporabljamo model GLEAMS. Učinek raznih ukrepov potem simuliramo s hidrodinamičnim modelom PCFLOW2D, rezultati so podani v obliki časovnega in prostorskega razporeda koncentracije onesnaženja v lagunah. To omogoča primerjavo učinka posameznih ukrepov ter določitev optimalnih. Shema metodologije uporabe dveh modelov za simulacijo poljedelskega onesnaževanja obalnih lagun je podana na sliki 1. Na koncu bo narejena tudi ekonomska primerjava posameznih ukrepov, kjer bomo upoštevali tako agronomske kot tudi marikulturne vidike ekonomskega vrednotenja.

1. PROBLEM DESCRIPTION

There are numerous coastal lagoons in Mexico, where mariculture represents an important economic source of income. The main products are fish, shellfish and shrimps. The regions around these coastal lagoons are often exploited by agriculture. In the regions of Sonora and Sinaloa there are more than 1 250 000 ha of agricultural area, which are irrigated and are situated in the neighborhood of 44 coastal lagoons with high fish production.

The problem is that fertilizers and pesticides are used to increase the agricultural production, and the irrigation water from the fields transports these contaminants into the lagoons, where they can contaminate marine food. Basically the nutrients, resulting from different fertilizers, have a damaging effect on the lagoon water quality, and in greater concentrations they can cause eutrophication. Pesticides are toxic and their allowed concentration in water bodies where mariculture is applied is very low.

The main goal of the research is to propose a methodology for ways of diminishing the concentration of nutrients and pesticides in the lagoons and for keeping it below some allowable limit. This will be achieved by the following steps.

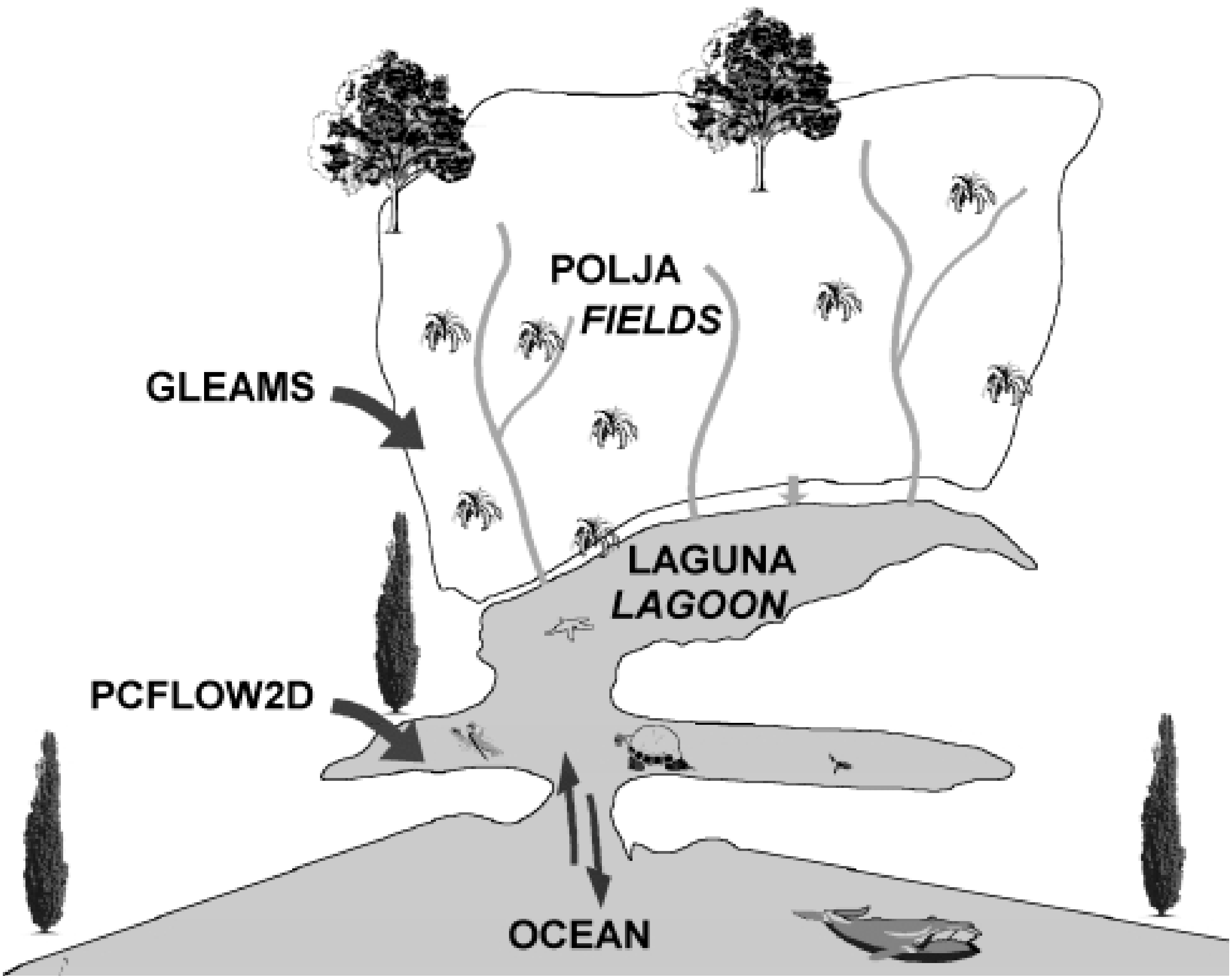
Firstly, it is necessary to determine possible measures for diminishing the input of fertilizers and especially pesticides from the agricultural area to the lagoons. Several possible remediation measures are studied, mainly in the form of improved agricultural management. The GLEAMS model is used for this purpose. The effect of different measures is further on simulated by the hydrodynamic and pollutant transport numerical model PCFLOW2D, and the results are given as spatial and temporal distribution of contaminant concentration inside the lagoons. This makes it possible to compare the effect of different remediation measures and to propose the optimum measures. Scheme of the modelling methodology for the simulation of agricultural pollution of a system of coastal lagoons is given in Figure 1. An economical evaluation of all the possible measures will also be carried out, where both agricultural and maricultural production will be taken into account.

V študiji so obravnavani tudi nekateri možni "hidravlični" ukrepi, npr.:

1. Izgradnja cevovodov, po katerih bi speljali onesnaženo vodo s polj neposredno v ocean. Ta rešitev je vprašljiva z ekonomskega vidika.
2. Zasaditev določenih rastlin v nekaterih delih lagun, ki odvzemajo hraniva iz vode, bi lahko pripomogla k izboljšanju kakovosti vode v lagunah.

Several possible "hydraulic" remediation measures will also be studied, e.g.:

1. To construct pipelines, which would conduct contaminated water from the fields directly to the open ocean. This solution is questionable from the economic point of view.
2. To grow water plants in some parts of the lagoons, which generate sufficient intake of nutrients and pesticides from the contaminated water, and thus improve water quality in the lagoons.



Slika 1. Shema metodologije uporabe dveh modelov za simulacijo poljedelskega onesnaževanja obalnih lagun.
Figure 1. Scheme of the modelling methodology for the simulation of agricultural pollution of a system of coastal lagoons.

Eden od lagunskih sistemov je v dolini Carizo v SZ Mehiki, v državi Sinaloa: lagune Bacorehuis, Jitzamuri, in Agiabampo. Celotna površina lagun je okrog 150 km^2 in v bližini je 46 000 ha poljedelskih površin, od koder se voda izteka v lagune. Lagune so v glavnem plitke, povprečna globina lagune Bacorehuis je 5 m, Agiabampo 2 m, globina južnega dela lagune Jitzamuri pa samo 1 m. Lagunski sistem je povezan s Tihim oceanom (oziroma s Kalifornijskim zalivom za polotokom Baja California) z ožino, ki ima največjo globino 13 m. Podrobnejši opis območja je v nadaljevanju članka (Četina et al., 2003).

Opravljena je bila predhodna študija modeliranja hidrodinamične cirkulacije in disperzije onesnaženja s teh poljedelskih območij in je opisana v drugem delu tega prispevka (Četina et al., 2003).

2. MODELIRANJE IZTOKA ONESNAŽEVALCEV S POLJEDELSKIH OBMOČIJ: MODEL G L E A M S

2.1 POLJEDELSKO UPRAVLJANJE

V svetu je dušik (N) glavni omejitveni dejavnik za celotno proizvodnjo hrane kot tudi za vsebnost proteina (Peterson & Frye, 1989), zato je pravilno upravljanje z dušikom izredno pomembno tako za proizvodnjo hrane, kot tudi za onesnaževanje okolja. V primeru obalnih lagun, ostanki namakalne vode, ki odteka s polj s seboj prinaša onesnaževalce in povzroča omenjeno onesnaževanje morske hrane.

Zato je pravilno upravljanje na poljih zelo pomembno za zmanjšanje onesnaževanja s hranivi in pesticidi. Tu gre predvsem za pravilno izbiro tipa hraniva, količine uporabljenega hraniva, metode aplikacije, pravilno izbiro časa gnojenja, vrste in količine pesticida, metode aplikacije pesticida ter pravilno izbira časa uporabe pesticidov.

One of the lagoon systems is situated in the Carizo valley in NW Mexico, in the Mexican state of Sinaloa: the lagoons Bacorehuis, Jitzamuri, and Agiabampo. The total area of the lagoon system is about 150 km^2 and there is 46 000 ha of agricultural area which is drained into the lagoons. The lagoons are mainly shallow, the average depth of Bacorehuis being 5 m, of Agiabampo 2 m, and the depth of the southern part of Jitzamuri only 1 m. The lagoon system is connected with the Pacific Ocean (in fact with the California Bay behind the Baja California peninsula) by a strait, with a maximum depth of 13 m. A more detailed description of the region is given in Četina et al. 2003.

A preliminary study of modelling of the transport–dispersion of contaminants from these agricultural regions has been carried out and is described in greater detail in the second part of this article (Četina et al., 2003).

2. MODELLING OF OUTFLOW OF CONTAMINANTS FROM FIELDS: THE G L E A M S MODEL

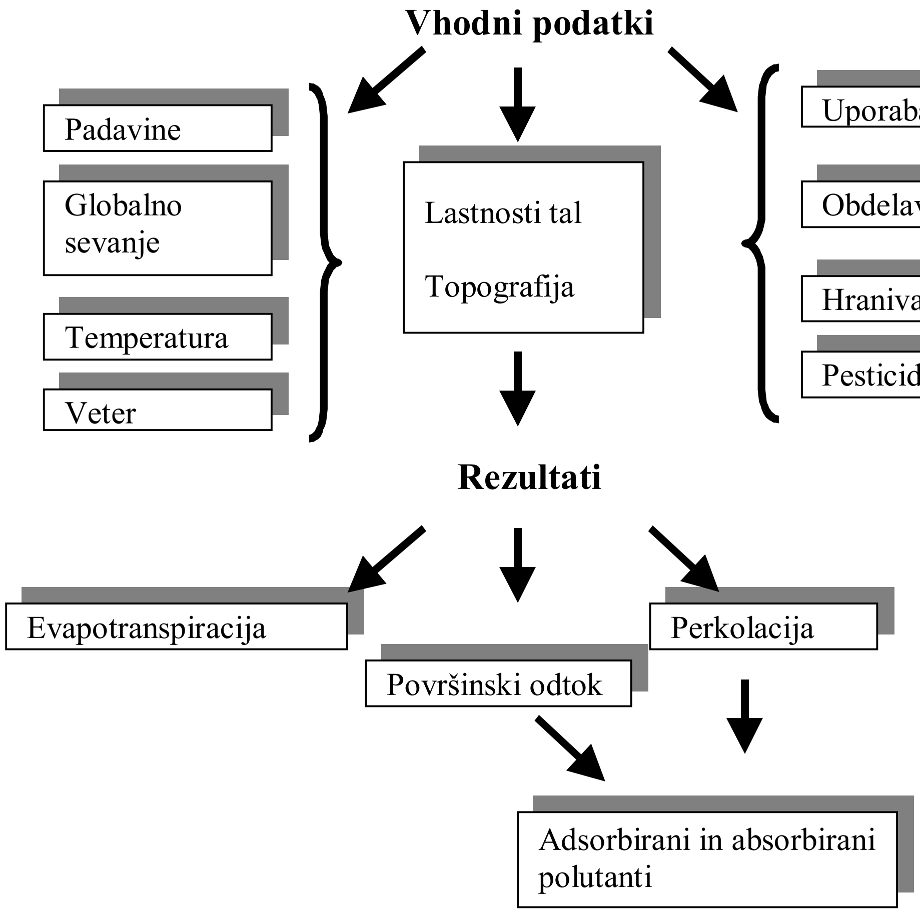
2.1 AGRICULTURAL MANAGEMENT

Since nitrogen (N) fertilizer supply is the primary nutrient limitation for both total world food production and protein content (Peterson & Frye, 1989), effective management of N is extremely important on the one hand for food production and, on the other hand, also for preventing contamination of the environment. In the case of coastal lagoons, the irrigation water brings contaminants into the lagoons, thus causing contamination of marine food.

Therefore proper agricultural management is of great importance for diminishing water contamination by fertilizers and/or pesticides. This involves the following decisions regarding the proper: type of applied fertilizer; amount of fertilizer; method of application; timing of fertilizer application; type of applied pesticides; amount of pesticide; method of pesticide application; timing of pesticide application.

Iz zgornjega je razvidno, da je prvi in pogosto najbolj učinkovit ukrep za zmanjšanje onesnaževanja vode v obalnih lagunah optimalno poljedelsko upravljanje. Ta metodologija bo bolj natančno opisana v tretjem delu prispevka (Pintar et al., 2003). Shema modela GLEAMS je podana na sliki 2.

From the above it can be understood, that the first, and often the most effective step in solving the problem of lagoon contamination is to determine optimum agricultural management. This methodology will be described more in detail in the third part of this paper (Pintar et al., 2003). A scheme of GLEAMS model is given in Figure 2.



Slika 2. Shema modela GLEAMS.

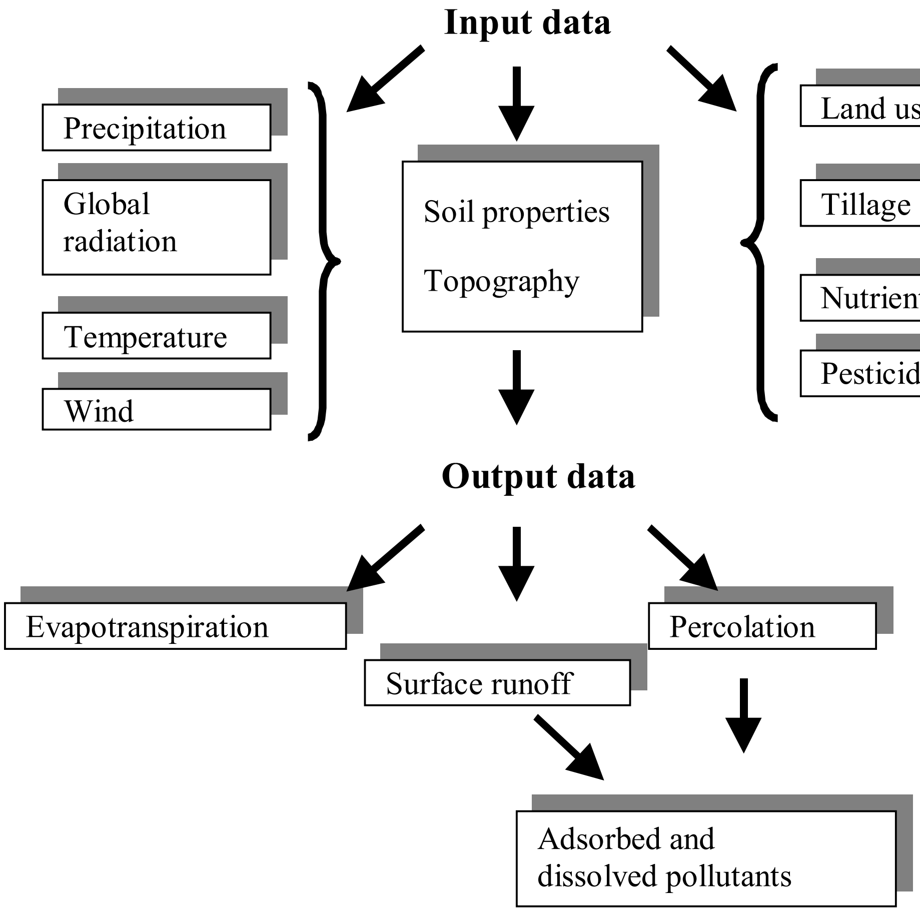


Figure 2. Scheme of GLEAMS model.

2.2. VPLIV KMETIJSTVA – UPORABA MODELA GLEAMS

Naslednji del raziskave mora dati odgovor na vprašanje: "Koliko mineralnih gnojil in fitofarmacevtskih sredstev se spere v lagune z opazovanega kmetijskega območja pri različnih scenarijih kmetijske prakse?" Vprašanje je pomembno za določitev vpliva posameznega scenarija in določitev najprimernejše kmetijske prakse. Pri tem se uporablja matematično modeliranje s posameznimi meritvami.

Eden najbolj uporabnih modelov, ki simulirajo omenjeni fenomen, je GLEAMS *(Groundwater Loading Effects of Agricultural Management Systems,* Obremenitve podtalnice ob upravljanju s poljedelskimi sistemi*)*, ver.

2.2 DETERMINATION OF THE EFFECT OF AGRICULTURAL MANAGEMENT – USE OF GLEAMS MODEL

The next part of the research must give an answer to the question: "What amounts of fertilizers and pesticides are being washed from the studied agricultural area into lagoons at each scenario of agricultural management?". This question is important in order to determine the effect of each scenario and then to find out the most appropriate management. Numerical modelling will be used for this purpose, together with some measurements.

One of the most appropriate models for simulating this phenomenon is the GLEAMS-Groundwater Loading Effects of Agricultural Management Systems, ver. 3.0. This is a mathematical simulation model developed for

3.0. Ta matematični simulacijski model so razvili za območja velikosti polja za ovrednotenje vplivov kmetijske prakse na gibanje snovi znotraj in skozi koreninsko talno plast. Model uporabljajo v več kot 40 državah, na voljo pa je tudi prek interneta.

Glavni *vhodni podatki* modela GLEAMS so:

– hidrološki podatki območja (dnevni podatki o padavinah in temperaturi; mesečni podatki o temperaturi, sončno sevanje, veter in temperatura rosišča),
– lastnosti tal,
– podatki o kmetijski kulturi,
– značilnosti fitofarmacevtskega sredstva in podatki o aplikaciji in
– gnojenje in podatki o obdelavi tal.

Rezultati modela so dnevni, mesečni in letni podatki:

– vodni tok (površinski ali podpovršinski ali oboje,
– premeščanje sedimentov,
– izgube hranil (količina in koncentracija),
– izgube fitofarmacevtskih sredstev (količina in koncentracija).

Kniesel (1995), ki je eden od avtorjev modela GLEAMS, je tega na kratko opisal:

Model GLEAMS je sestavljen iz štirih komponent, ki potekajo sočasno: hidrologija, erozija/nanos materiala, fitofarmacevtska sredstva in rastlinska hranila.

Hidrologija. Simulirana je dnevna vodna bilanca za talni sistem v koreninski coni. Model razporedi talne značilnosti na največ 12 računskih plasti, pri tem imajo tla do pet talnih horizontov. Izračunana je dnevna potencialna evapotranspiracija, odtok, dostopna količina vode v tleh, odtok skozi talni profil in namakanje.

Erozija. Komponenta erozije je modifikacija Universal Soil Loss Equation (USLE). Faktor erozivnosti (R) iz omenjene enačbe nadomesti energija dežja v posameznem deževnem dogodku. Premeščanje sedimentov se računa na podlagi specifičnega pretoka, ki ga v hidrogeološki komponenti računamo iz simuliranega največjega površinskega odtoka za nevihto na iztoku z območja.

field-size areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone. The model is widely used in over 40 countries and is available on the Internet.

The basic *input data* for the GLEAMS model are:

– Hydrologic data of the region (daily rainfall and temperature; monthly temperature, solar radiation, wind movement, and dewpoint temperature),
– Soil characteristics
– Crop situation,
– Pesticide characteristics and application data, and
– fertilization and tillage data.

The model *output results* are various-daily, monthly, annual:

– Water flow (either surface or groundwater or both),
– Sediment transport,
– Nutrient outflow (mass and concentration),
– Outflow of pesticides (mass and concentration).

Kniesel (1995) is one of the authors of the GLEAMS model. He briefly describes the model:

The GLEAMS model consists of four components operating simultaneously: hydrology, erosion/sediment yield, pesticides, and plant nutrients.

Hydrology. Daily water accounting is simulated in a soil system layered within the soil horizons of the root zone. The model distributes soil characteristics into a maximum of 12 computational layers with input from a maximum of 5 soil horizons. Daily potential evapotranspiration is calculated, as well as runoff, available water storage, percolation through the soil layers, and irrigation.

Erosion. The erosion component is the modification of the Universal Soil Loss Equation (USLE). The erosivity (R) factor of the USLE is replaced by storm-by-storm rainfall energy calculated from daily rainfall. A characteristic discharge, calculated from the storm runoff peak rate simulated at the field outlet in the hydrogeology component, is used to calculate sediment transport.

Fitofarmacevtska sredstva. Komponenta fitofarmacevtskih sredstev vključuje površinski tok, kot je določen v modelu CREAMS z vertikalnim tokom ter definira pot fitofarmacevtskih sredstev v, znotraj ter skozi koreninsko cono. Adsorpcija fito-farmacevtskega sredstva na talni organski ogljik se uporablja za razdelitev komponente med talno raztopino in tlemi za simulacijo izluževanja v površinski odtok, sediment in perkolirano vodo. Razgradni produkti (metaboliti) se upoštevajo, kadar so znane njihove značilnosti. Sočasno se lahko simulira 10 fitofarmacevtskih sredstev z razgradnimi produkti. Simulacija izgub fitofarmacevtskih sredstev poteka v površinskem odtoku, sedimentu in perkolatu na spodnjem robu koreninske cone.

Rastlinska hranila. Pri rastlinskih hranilih sta upoštevana dušik in fosfor. V modelu sta obravnavana njuna obsežna ciklusa. Aplikacija anorganskih gnojil upošteva površinsko aplikacijo, inkorporacijo v tla in fertigacijo. Živinski odpadki, s podatkom o vsebnosti hranil, so lahko aplicirani površinsko, lahko so inkorporirani ali injektirani v tla, lahko so porabljeni kot iztoki iz lagun. Algoritmi obdelave in temperature tal so vključeni v komponento hranil. Dušik v padavinah je vhodni podatek, vezan na območje aplikacije modela. Kjer so koncentracije v vodnem viru večje, se v vodi za namakanje dušik in fosfor upoštevata.

Kmetijska praksa. GLEAMS je bil razvit za primerjavo odzivov različnih kmeijskih praks na podnebje. Model mora biti sposoben za predstavitev širokega izbora kmetijskih praks. Dobri in slabi hidrološki pogoji kategorizirajo sposobnost tal za infiltracijo dežja. Metoda torej predstavlja kmetijsko prakso s simulacijo kontinuiranega odtoka.

S pomočjo GLEAMSa lahko naredimo izbor fitofarmacevtskih sredstev za specifična tla in kolobar, glede na značilnosti fitofarmacevtskega sredstva. Če lahko ustrezno kontrolo dosežemo z alternativnim fitofarmacevtskih sredstvom, izberemo v smeri zmanjšane izgube preko površinskega toka ter perkolacije.

Pesticides. The pesticide component incorporates the surface pesticide flux response to CREAMS with a vertical flux component to route pesticides into, within, and through the root zone. Characteristics of pesticide adsorption to soil organic carbon are used to partition compounds between solution and soil fractions for simulating extraction into runoff, sediment, and percolation losses. Degradation products, (metabolites) can be considered when their characteristics are known. Up to 10 pesticides can be simulated simultaneously, including metabolites. Pesticide losses are simulated in runoff, with sediment, and in percolate at the bottom of the root zone.

Plant nutrients. The plant nutrient component considers nitrogen and phosphorus. Comprehensive nitrogen and phosphorus cycles are treated in the model. Inorganic fertilizer application considers surface application, incorporation, and fertigation. Animal waste application, with specification of nutrient content, may be represented as surface, incorporation, injection, or liquid such as lagoon effluent. Tillage and soil temperature algorithms are included in the nutrient component. Rainfall nitrogen is the input for the model application site, and N and P in irrigation water can be considered for locations where concentrations in the water supply may be significant.

Management. GLEAMS was developed to compare the responses of alternate management practices to long-term climate. The model must be capable of representing a wide range of management practices. Good and poor hydrologic conditions have further categorized receptiveness of the soil for rainfall infiltration. Thus, the method represents management in the continuous runoff simulation procedure.

A selection of pesticides for specific soil and cropping systems can be made with the GLEAMS model based upon pesticide characteristics. If adequate control can be achieved with alternate pesticides, selection can be made to minimize runoff losses or to minimize percolation losses.

Pri hidrologiji se upošteva posamezna kultura, vendar pa se lahko upošteva tudi sestavljen indeks listne površine. Kolobar, ki vljučuje več kultur, predstavlja intenzivno kmetijsko prakso, ki jo lahko upoštevamo v GLEAMS-u.

GLEAMS se uporablja v več kot 40 državah v Severni Ameriki ter Evropi. Njegovo uporabo priporoča tudi American Environmental Protection Agency. Dobri rezultati validacije programa so bili doseženi le v primerih, ko so bili uporabljeni lokalni parametri, kar priporočajo tudi avtorji modela (Wu et al., 1996; 1997). Uporabljen je tudi za definiranje strategije zaščite podtalnice (Diebel et al., 1992). V slovenskih razmerah je bil GLEAMS uporabljen za spremljanje atrazina v tleh in je dal zadovoljive rezultate (Turk, 1995).

Vhodni podatki za model GLEAMS so odvisni od scenarija kmetijske prakse. Kot rezultat model pokaže vpliv kmetijske prakse, zato je model GLEAMS uporaben za določitev prvih učinkov kmetijske prakse: iztok onesnaževal s kmetijske površine v lagune.

2.3 MERITVE

Za umerjanje in preverjanje modela GLEAMS morajo biti izvedene nekatere meritve (od katerih, jih je del že opravljen):

- *Tla:* globina, tekstura, gostota tal, poroznost, poljska kapaciteta tal za vodo, točka venenja, vsebnost organske mase, pH, nasičenost z bazami, vsebnost kalcijevega karbonata. Vzroci tal bodo vzeti z določene globine tal.
- *Površina:* oblika, naklon
- *Podnebje:* dnevne padavine, dnevne temperature. Ostali podnebni podatki so manj občutljivi in so lahko pridobljeni in obstoječih nizov podatkov za območje.

Naslednji parametri bodo merjeni na iztoku vode s kmetijske površine:

- površinski odtok vode,
- perkolacija,
- količina sedimenta,

A single crop is assumed in hydrology, but a composite leaf area index can be input. Crop rotation including multiple cropping, that is growing more than one crop during a year, represents intensive management that can be considered in GLEAMS.

GLEAMS is used in over 40 North American and European countries. Its use is also recommended by the American Environmental Protection Agency. Good results for program validation were obtained only in those cases where local parameters were used, which is also recommended by the program's authors (Wu et al., 1996; 1997). It is used to define the ground water protection strategy, as well (Diebel et al., 1992). In the Slovene environment, GLEAMS has been used to monitor atrazine in soil and yielded satisfactory results (Turk, 1995).

The input data for the GLEAMS model depend on the scenario of the agricultural management. Since the model output results show the effect of the management, the GLEAMS model can be used to determine the first effect of the management: the output of contaminants from agricultural area into the lagoons.

2.3 MEASUREMENTS

To calibrate and verify the GLEAMS model several measurements should be carried out, (some of them already done):

- *Soil:* soil depth, soil texture, soil bulk density, soil porosity, field water capacity, wilting point, content of organic mater in soil, pH, base saturation, calcium carbonate content. Soil samples will be taken to a certain depth.
- *Area:* shape, inclination
- *Climate:* daily rainfall, daily temperature. Other climate data are less sensitive and should be gathered from existing sets of climate data for the region.

The following parameters will be measured in the outflow water from the agricultural area:

- water runoff,
- water percolation,
- sediment yield,

- uporabljena fitofarmacevtska sredstva bodo merjena v površinskem odtoku, sedimentu, v tleh in v perkolirani vodi,
- nitratni-N v površinskem odtoku, tleh in perkolirani vodi,
- amonijski-N v površinskem odtoku, sedimentu in tleh in
- fosfor v površinskem odtoku, sedimentu in tleh.

Vodni vzorci bodo vzeti na iztoku površinskih in/ali podzemnih drenov.

V letu 1998 je bila opravljena serija meritev (González-Farias, 1998). Merjeni so bili naslednji parametri: padavine, koncentracija skupnega fosforja in skupnega dušika v sedimentu drenov, lagun in v Oceanu.

3. MODELIRANJE CIRKULACIJE IN DISPERZIJE KONTAMINANTOV V LAGUNAH

3.1 PCFLOW2D MODEL

Naslednji korak raziskave je določiti krajevni in časovni razpored koncentracije kontaminantov v lagunah, kjer upoštevamo vse opisane ukrepe za izboljšanje stanja. Določili bomo tudi, če je v katerikoli lokaciji presežena dopustna koncentracija. Tu smo uporabili dvo-dimenzionalni (2D) model PCFLOW2D. Ta lahko v tem primeru nadomesti bolj kompleksno 3D verzijo modela, saj so lagune zelo plitve (globine so večinoma pod 5 m) v primerjavi s horizontalnimi dimenzijami (več deset km) in večinoma ne pričakujemo večje toplotne ali slanostne stratifikacije.

- pesticides which will be used on the observed field, will be measured in runoff, sediment, soil and percolated water,
- nitrate-N in runoff, soil and percolated water,
- ammonia-N in runoff, sediment and soil, and
- phosphorus in runoff, sediment and soil.

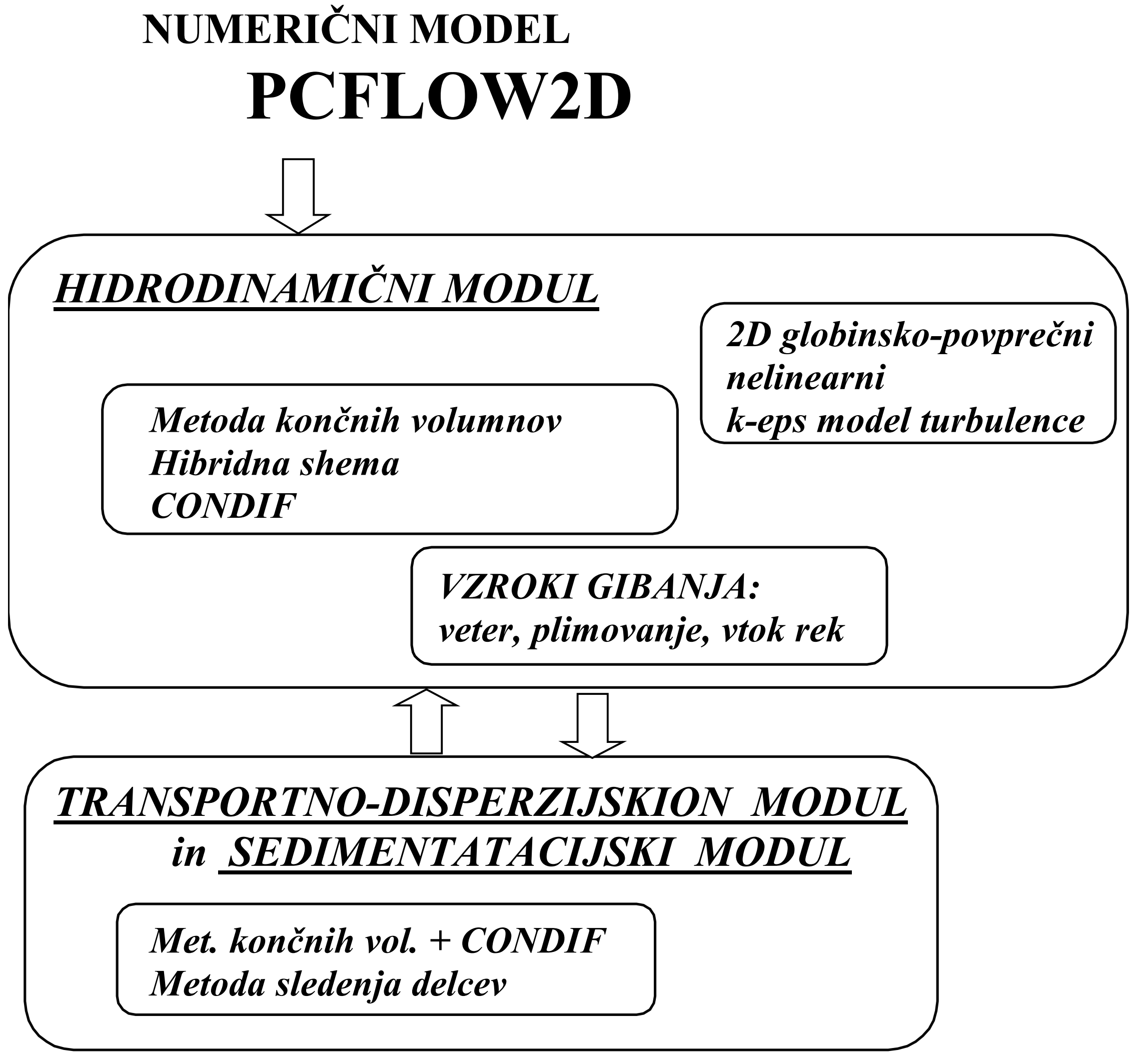
Water samples must be taken at the mouths of the surface and/or underground drains.

In 1998, a measuring campaign was carried out (González-Farias, 1998). The following parameters have been measured: precipitation, concentration of total phosphorus and total nitrogen in the bottom sediment of the drains, lagoons and in the Ocean.

3. MODELLING OF CIRCULATION AND DISPERSION OF CONTAMINANTS IN THE LAGOONS

3.1 PCFLOW2D MODEL

The next step of the research is to determine the spatial and temporal distribution of contaminant concentration inside the lagoons, taking into account all the described agricultural and hydraulic remediation measures. This will give information as to whether at any location the allowable limit is exceeded. This is carried out using a two-dimensional numerical model PCFLOW2D. This can replace here the more complex 3D version, as the lagoons are very shallow (the depth is mostly less than 5 metres) in comparison to the horizontal dimensions (several tens of kilometers) and mostly no significant thermal or salinity stratification is expected.



Slika 3. Shema numeričnega modela PCFLOW2D.

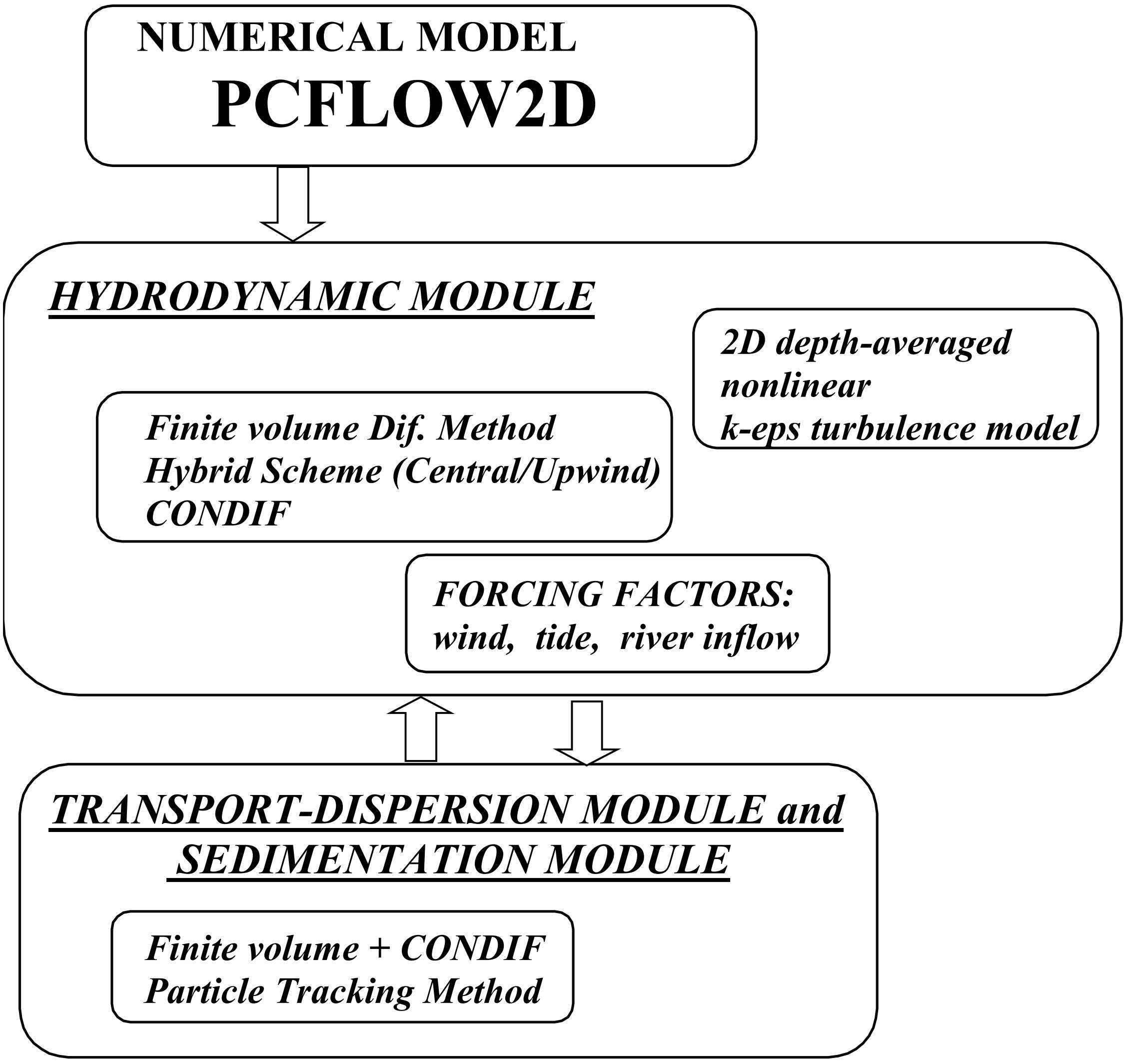


Figure 3. Scheme of the numerical model PCFLOW2D.

Model je bil razvit na univerzi v Ljubljani za simulacijo 2D tokov v rekah – z uporabo samo hidrodinamičnega modula (glej sliko 3). Kasneje je bil razvit transportno–disperzijski modul za simulacijo širjenja nekaterih polutantov v površinskih vodah. Ker je bil model že večkrat podrobno opisan (Rajar, 1992; Rajar & Četina 1997), tu podajamo le najosnovnejši opis.

Hidrodinamični modul. V tem delu se rešuje kontinuitetna enačba in 2D, globinsko povprečne dinamične enačbe. Uporabljamo metodo končnih prostornin s hibridno shemo (kombinacija centralne in 'upwind' sheme). Lahko upoštevamo naslednje robne pogoje (R.P.) *v poljubnih celicah* računskega

The model was first developed at the University of Ljubljana to simulate 2D flow in rivers – using only a hydrodynamic module (see Figure 3). Further on the transport-dispersion module was developed to simulate transport and mixing of different contaminants in surface waters. As the model has been described in detail in several papers (Rajar, 1992; Rajar & Četina 1997), here only a brief description is given.

Hydrodynamic (HD) module. It solves the continuity and the 2D depth integrated momentum equations. It is based on the finite volume numerical method of solution with the hybrid (central/upwind) solution scheme. The following boundary conditions (B.C.) can be used *at arbitrarily chosen cells* of the computational domain: a) Solid boundaries področja: a) trdne stene (normalne hitrosti so nič); b) vtok rek (predpisane so hitrosti ali pretoki); c) podajamo globine ali kote gladine; d) kritični tok; e) enačba preliva. *Vzdolž odprtih robov* so mogoči naslednji robni pogoji: a) znana krivulja plimovanja ali druga podana časovna funkcija spreminjanja gladine; b) "radiacijski" robni pogoj; c) "kontinuitetni" robni pogoj. Vpliv vetra je mogoče upoštevati skupaj s katerim koli drugim robnim pogojem, tako da podamo hitrost vetra in trenjski koeficient.

Transportno-disperzijski modul temelji na advekcijsko-difuzijski enačbi in simulira transport in disperzijo konzervativnih onesnaževalcev. Za nekatere specifične polutante (npr. nafta ali živo srebro), so vključeni nekateri biokemični procesi. Zaradi uporabe hibridne numerične sheme je prisotna določena numerična difuzija, ki lahko v določenih pogojih povzroči, da je točnost rezultatov vprašljiva. Zato smo razvili drugo različico modula, ki temelji na Lagrange-jevski metodi sledenja delcev (MSD). Ta metoda nima numerične difuzije in jo je mogoče učinkovito uporabiti za simulacijo disperzije polutantov iz točkovnih virov. V primeru tega projekta smo uporabili metodo MSD.

(with zero normal velocities); b) Inflow of rivers (discharges or velocities can be prescribed); c) Water depths or water surface elevations; d) Critical flow; e) Equation of a weir. *Along the open boundaries* the following boundary conditions can be used: a) known tidal or other time–dependent functions of the water surface; b) "radiation" boundary condition; c) "continuity" boundary condition. *Wind stress* can be taken into account with all boundary conditions by giving the wind speed and the wind friction coefficient.

Transport-dispersion (TD) module is based on the advection-diffusion equation and simulates transport and dispersion of any conservative contaminant. For some specific contaminants (eg. oil or mercury), bio-chemical processes are also included. Due to the application of the hybrid (central–upwind) scheme, a certain amount of numerical diffusion is present, which can in some cases render the results unreliable. Therefore another version of this module was developed, which is based on the Lagrangian Particle Tracking Method (PTM). This method is free of numerical diffusion and can be especially effectively used for simulation of pollutant dispersion from point sources. For the simulations of contaminant dispersion in the lagoons of Carizo valley this PTM method was used.

3.2 METODOLOGIJA

Slika 3 prikazuje temeljno metodologijo in povezavo modelov GLEAMS in PCFLOW2D. Lahko vidimo, da so izhodni rezultati modela GLEAMS, to je iztok vode, sedimentov, hraniv in pesticidov s poljskih površin, istočasno vhodni podatki za model PCFLOW2D. Ta model računa hidrodinamično cirkulacijo vode v lagunah. Največkrat na cirkulacijo v največji meri vpliva plimovanje, vendar upoštevamo tudi vpliv vetra in vtoka rek. Potem s transportno-disperzijskim modulom simuliramo širjenje onesnaževalcev v vodi. Končni cilj raziskave je dobiti prostorski in časovni razpored koncentracije hraniv in pesticidov v lagunah za vsak predpostavljeni scenarij. Primerjava razporeda koncentracije za predpostavljene

3.2 METHODOLOGY

Figure 3 shows the basic methodology, and linking of models GLEAMS and PCFLOW2D. As can be seen, the output results of GLEAMS i.e. information on water discharge, sediments, nutrient and pesticide concentration in the drain water from the fields are the input data for PCFLOW2D. Running this model, first the HD module calculates the hydrodynamic circulation of water in the lagoons. Usually the most important forcing factor, causing the water circulation in coastal lagoons is tide, but the influence of wind and river inflow is also taken into account. Further on, the transport-dispersion module simulates the transport and mixing of contaminants in the water. The final goal of the research is to obtain the spatial and temporal distribution of nutrient and pesticides concentration in the lagoons for each scenario. Comparing the resulting contaminant distribution for each scenario indicates the scenarije pokaže optimalne rešitve.

Kot je že omenjeno, so že izvedene simulacije cirkulacije v lagunah ob dolini Carizo opisane v članku Četina et al. (2003).

3.3 MERITVE

Za umerjanje in verifikacijo modela PCFLOW2D bomo izvedli v lagunskem sistemu doline Carizo naslednje meritve (da bi postopek ekonomizirali, bo število meritev reducirano na minimum in bomo uporabljali preproste metode meritev, kjerkoli je mogoče):

- Meritve gladin kot funkcija časa v 2 do 3 lokacijah v lagunah.
- Meritve hitrosti toka v 2 do 3 lokacijah v lagunah.
- Meritve disperzije sledila v lagunah.

Merjeni potek gladin bomo primerjali s simuliranimi. Spremembe gladine večinoma povzroča plimovanje na odprtem robu, manjši del sprememb gladine povzroči tudi veter, katerega vpliv je tudi upoštevan v modelu. Za umerjanje in verifikacijo transportno–disperzijskega modula, bomo merili časovni potek disperzije sledila. Uporabljali bomo razgradljivo sledilo, ki ne onesnažuje okolja.

4. ZAKLJUČKI

V tem delu članka je opisana metodologija reševanja. Cilj je doseči izboljšano poljedelsko upravljanje, oziroma zmanjšati vnos hraniv in pesticidov v lagune. Simulacije z modeloma GLEAMS in PCFLOW2D bodo pomagale določiti optimalne možne ukrepe.

Drugi del članka (Četina et al., 2003) opisuje simulacije hidrodinamične cirkulacije in disperzije onesnaževalcev v lagunah doline Carizo. V tretjem delu (Pintar et al., 2003) bo opisana uporaba modela GLEAMS za simulacijo različnih metod poljedelskega upravljanja v sistemu doline Carizo v SZ Mehiki.

optimum solutions.

As already mentioned, several simulations of the circulation and contaminant dispersion in the coastal lagoons of the Carizo valley are presented in Četina et al. (2003).

3.3 MEASUREMENTS

To calibrate and verify the model PCFLOW2D, the following measurements will be carried out in the lagoons (in order to economize, these measurements will be reduced to the minimum, and simple measuring methods will be used, whenever possible):

- Measurements of water level elevations as a function of time at two to three locations inside the lagoons.
- Measurements of velocity at two to three locations in the lagoons.
- Measurements of tracer dispersion in the lagoons.

Measured water level elevations will be compared with the simulated elevations. Mainly the water level rise is caused by the tidal fluctuation, a small part of the elevation may be due to wind forcing, which is also taken into account in the model. To calibrate and verify the transport–dispersion part of the model, a tracer will be put into the lagoon and the time development of its dispersion will be measured. A degradable tracer will be used, with no harmful effects for the environment.

4. CONCLUSIONS

The methodology to be used to solve this problem is described in this part of the paper. Improved agricultural management will be studied, the effect will be simulated by two models: GLEAMS and PCFLOW2D. Simulations will help determine the best solution.

The second part of the paper (Četina et al., 2003) describes hydrodynamic and contaminant transport simulations, and the third part (Pintar et al., 2003) will describe the use of the GLEAMS model to simulate several possible agricultural management methodologies in the system of the Carizo valley, NW Mexico.

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