stowa

VOORSPELLINGSSYSTEEM DRIJFLAGEN VAN BLAUWALGEN

RAPPORT 2009 14

stowa

VOORSPELLINGSSYSTEEM DRIJFLAGEN VAN BLAUWALGEN

RESULTATEN PILOTS 2008

RAPPORT 2009 **14**

ISBN 978.90.5773.429.8

stowa@stowa.nl WWW.stowa.nl
TEL 030 232 11 99 FAX 030 231 79 80
Arthur van Schendelstraat 816
POSTBUS 8090 3503 RB UTRECHT

Publicaties van de STOWA kunt u bestellen op www.stowa.nl.
Deze publicatie is alleen digitaal beschikbaar.

COLOFON

Utrecht, 2009

Uitgave
STOWA 2009
Arthur van Schendelstraat 816
Postbus 8090
3503 RB Utrecht
Tel 030 2321199
Fax: 030 2321766
e-mail: stowa@stowa.nl
http://www.stowa.nl

Auteurs
David Burger (Deltares)
Rolf Hulsbergen (Deltares)
Hans Los (Deltares)
Simon Groot (Deltares)
Bas Ibelings (NIOO)

Begeleidingscommissie:
Jasper Stroom (Waternet), voorzitter
Wil van der Ende (Hoogheemraadschap Delfland)
Johan Oosterbaan (Hoogheemraadschap Rijnland)
Tineke Burger (Rijkswaterstaat IJsselmeergebied)
Michelle Talsma (STOWA)
Wolf Mooij (NIOO)

Prepress/druk
Van de Garde | Jémé

STOWA
Rapportnummer 2009-14
ISBN 978.90.5773.429.8

TEN GELEIDE

Drijflagen van blauwalgen vormen een jaarlijks terugkerend probleem in een flink deel van de Nederlandse meren en plassen. Vooral bij zwemlocaties is de overlast groot. De zichtdiepte vermindert, er kan stankoverlast optreden en er kunnen hoge toxinegehaltes ontstaan.
In de nieuwe EU zwemwaterrichtlijn, alsmede in het concept Nationaal Waterplan worden blauwalgen genoemd als een gezondheidsrisico waar tijdig en adequaat mee omgegaan moet worden. Een modelinstrumentarium waarmee een algenbloei enkele dagen van tevoren kan worden voorspeld kan een waterbeheerder helpen met het nemen van beslissingen om maatregelen te treffen en waarschuwingen te geven om recreanten te beschermen.
De doelstelling van dit project is om een waarschuwingssysteem te ontwikkelen dat drijflaagvorming door blauwalgen in kleine en grote binnenwateren kan voorspellen. Met het waarschuwingssysteem moet per meer of plas een aantal dagen vooruit voorspeld kunnen worden waar en wanneer drijflagen zullen ontstaan.

In 2007 is gestart met de bouw van het waarschuwingssysteem en is het model toegepast in een viertal meren. In 2008 is dit onderzoek doorgezet. In zowel 2007 als 2008 bleef de blauwalgenbloei door de relatief slechte zomers (weinig zon, veel wind) beperkt. Hierdoor zijn in beperkte mate gegevens beschikbaar om te kunnen toetsen of het model goed scoort. Uit de resultaten blijkt dat in veel gevallen drijflagen die ook daadwerkelijk worden waargenomen correct worden voorspeld, maar dat er nog te veel 'false positives' optreden. Hierbij voorspelt het model een algenbloei maar treedt deze in werkelijkheid niet op.

Besloten is om in 2009 opnieuw de drijflaagvorming bij de deelnemende waterbeheerders in beeld te gaan brengen. Hierbij zullen in het Gooi en Eemmeer ook nieuwe technieken zoals de fluoroprobe, een webcam en vliegtuig remote sensing worden ingezet. Daarnaast wordt fundamenteel onderzoek verricht om de factoren die drijflaagvorming beïnvloeden te kunnen kwantificeren.

Mei 2009,

J.M.J. Leenen
Directeur STOWA

SAMENVATTING

Jaarlijks zijn veel zwemwaterlocaties gesloten voor zwemmers vanwege drijflagen van blauwalgen. De klimaatverandering heeft als neveneffect dat intensiteit en frequentie van blauwalgenbloei verder zal toenemen. Vanwege (inter)nationale verplichtingen wordt de druk groter om de blauwalgenproblematiek aan te pakken, waarbij drijflagen de kern vormen van het blauwalgenprobleem. In het concept Nationale Waterplan (versie augustus 2008) wordt expliciet melding gemaakt van blauwalgenproblematiek als zijnde de belangrijkste oorzaak van zwemverboden en negatieve zwemadviezen. Zowel effectgerichte als structurele maatregelen dienen volgens het waterplan meer handen en voeten te krijgen. In het vernieuwde blauwalgenprotocol (Werkgroep Cyanobacteriën, 2008) wordt de nadruk gelegd op drijflaagvorming omdat met drijflagen de grootste risico's en overlast gepaard gaan. Voor de burger en recreatie-gerelateerde bedrijvigheid aan het water is de aanwezigheid van (drijflagen van) blauwalgen een direct meetbare en zeer negatieve parameter. Het levert beperking van zwem- en recreatiemogelijkheden en stankoverlast op.

Door Deltares is in 2007 in opdracht van STOWA het drijflaagvoorspellingsmodel EWACS ontwikkeld. Het model geeft een 7-daagse verwachting van de kans op het optreden van blauwalgenbloei, gegeven de weersverwachting en de lokale omstandigheden in meren en plassen. Doel is invulling te geven aan de zwemwaterrichtlijn door (1) het tijdig waarschuwen voor drijflagen en (2) het beheer van drijflaagbestrijdende en -werende maatregelen tijdig aan te kunnen sturen. Het model gebruikt een versimpelde versie van het 3-dimensionale oppervlaktewatermodel Delft3D, in combinatie met een drijflaagmodule gebaseerd op EcoFuzz. Alle erkende Nederlandse blauwalgenexperts zijn direct of zijdelings betrokken geweest bij de kennisregels die nodig zijn om drijflagen te voorspellen.

Het drijflaagvoorspellingsmodel is in de jaren 2007 en 2008 uitgetest op vier proeflocaties: de Westeinderplassen, de Delftse Hout, de Sloterplas, en het Gooi- en Eemmeer. Locatiespecifiek kan het model kansen op drijflaagvorming uitrekenen en grafisch weergeven. Helaas voldoen de resultaten voor de proeflocaties (nog) niet aan de eisen en verwachtingen. Dit wordt mede veroorzaakt doordat er in 2007 en 2008 weinig grote problemen met blauwalgendrijflagen zijn opgetreden en door de moeilijkheid om op de testplassen op ieder moment te bepalen of er wel of geen drijflagen zijn. Daarnaast lijkt het rekenhart van het model nog niet voldoende in staat om adequate voorspellingen van het verschijnen en verdwijnen van drijflagen te genereren. Er is met het bestaande model gebaseerd op EcoFuzz gewerkt, maar vooral in 2008 zijn ook nieuwe rekenregels uitgetest. De resultaten van dit project 'EWACS (Early Warning Against Cyano Scums)' zijn verwoord in STOWA rapport 2008-11 "Voorspellingssysteem blauwalgen [Resultaten pilots 2007]" en STOWA rapport 2009-14 "Voorspellingsysteem blauwalgen [Resultaten pilots 2008]". De rapporten zijn te downloaden via www.stowa.nl.

EWACS-onderzoek 2008

Het prototype van het EWACS voorspellingsmodel is in 2008 in een operationele setting opnieuw getest met de binnenkomende wekelijkse veldgegevens, aangevuld met de door het KNMI gemeten en voorspelde meteorologische parameters voor de vier proefgebieden. Door de operationele setting in 2008 is tevens de samenwerking tussen de deelnemende waterbeheerders, de bemonsteringsteams, de deelnemende laboratoria en het EWACS-modelleringsteam getest om binnen de beschikbare tijd een waarschuwingsbulletin te produceren. Op basis van de evaluatie van het onderdeel gegevensverzameling en -analyse zijn een aantal

aanbevelingen gedaan, die vooral de leveringssnelheid en het format van de waterkwaliteitsdata betreffen. Hoewel het model relatief weinig invoergegevens nodig heeft, betreft het voor een deel arbeidsintensieve parameters. Daarnaast wordt de bepaling van het algen biovolume alleen uitgevoerd door externe laboratoria waardoor aanzienlijke vertragingen kunnen optreden, wat nog wordt versterkt doordat de piek in cyanobacteriën samenvalt met de zomervakanties. In de meeste gevallen waarin niet op tijd een waarschuwingsbulletin kon worden geproduceerd lag dat aan de vertraagde levering van algen celtellingen en chlorofyl-a bepalingen. Omdat in de huidige modelopzet de algen-biomassa niet wordt gemodelleerd, zijn deze invoergegevens essentieel voor het EWACS drijflaagvoorspellingsmodel. Onderzocht moet worden in hoeverre fluoroprobes gebruikt kunnen worden om de afhankelijkheid van de algen biovolumes te verminderen.

Op 9 september 2008 is in Utrecht de EWACS workshop ‘Blauwalgen drijflagen’ georganiseerd waarbij de belangrijkste Nederlandse blauwalgenexperts aanwezig waren. Tijdens die workshop zijn de opzet, de uitgangspunten en de knelpunten van het EWACS-drijflagenmodel besproken. De aanwezigen onderschreven de stelling om voorlopig door te gaan met een op fuzzy logic gebaseerde model-aanpak in plaats van de gebruikelijke deterministische beschrijving. De experts hebben daarnaast een aantal suggesties gedaan, waarvan de belangrijkste zijn het toevoegen van het lichtniveau *in* de waterkolom in plaats van in de atmosfeer, het toevoegen van de ‘langere termijn lichtgeschiedenis’ en het toevoegen van de strijklengte als verklarende variabele. Volgens de aanwezigen kunnen experimenten in mesocosms beter zicht geven op de vraag welke biomassa in het veld hoort bij een categorie 2 drijflaag. Ook kunnen mesocosms worden gebruikt om te testen onder welke omstandigheden drijflagen worden gevormd en weer verdwijnen. Bij de monitoring wordt een onderscheid gemaakt in 3 categorieën drijflagen, variërend van licht (categorie 1) tot middel (categorie 2) naar zwaar (categorie 3). Deze categorieën komen overeen met die van het eerder genoemde blauwalgen-protocol. Vanaf categorie 2 spreken we van een relevante drijflaag.

Modelaanpassingen 2008

Omdat de gebruikte modelformuleringen kwalitatief onvoldoende drijflagen voorspelden, is een aantal verfijningen doorgevoerd in de processen die het verschijnen en verdwijnen van drijflagen beschrijven. Daarnaast is een aantal wijzigingen in het format van de invoergegevens uitgeprobeerd om de grote variatie in sommige meetgegevens te verminderen (zoals de windsnelheid). Vervolgens is met deze aangepaste modelformuleringen de omvang van blauwalgen-drijflagen gesimuleerd voor de omstandigheden in de zomer van 2008. Tenslotte is EcoFuzz stand-alone toegepast op de gegevens van het jaar 2006 als een eerste test voor de model performance in een jaar met meer drijflagen.

Resultaten 2008

Gebaseerd op de wekelijks verzamelde gegevens en (meteo)voorspellingen, is iedere week een simulatie met het EWACS drijflagenmodel uitgevoerd voor de vier proefgebieden en is op basis daarvan een bulletin geproduceerd ten behoeve van de waterbeheerders. De modelresultaten zijn over het algemeen matig voor alle proefgebieden, behalve voor het Gooi- en Eemmeer waar hogere scores werden gehaald die slechts ten dele kunnen worden toegeschreven aan de beperkte hoeveelheid validatiemateriaal. Dit betekent dat de overeenstemming tussen modelvoorspelling en waarneming nog onvoldoende is. Dit wordt bevestigd door de berekening van Cohen’s Kappa, een statistische test die overeenstemming tussen twee datasets berekent.

Als gebruik wordt gemaakt van meetgegevens van de werkelijk opgetreden situatie in plaats van de voorspelde (meteo)omstandigheden, dan wordt het modelresultaat nauwelijks beter. In de Delftse Hout, Sloterplas en Westeinderplassen worden een groot aantal 'false positives' (drijflaag wordt door het model voorspeld maar niet waargenomen in het veld) geteld, vooral door de hoge kans op het ontstaan van drijflagen die door het model voor die perioden wordt berekend. Dit verschijnsel trad ook op bij de modelsimulaties in 2007.

Een gedetailleerde analyse van de meetgegevens en modelsimulaties voor de Delftse Hout gaf aan dat de 'false negatives' (drijflaag wordt niet door het model voorspeld maar wel waargenomen in het veld) vaak worden veroorzaakt door de gemeten hoge windsnelheid op het moment dat in het veld een drijflaag is waargenomen. Een hoge windsnelheid wordt door het model juist vertaald naar een geringe kans of zelfs afwezigheid van een drijflaag. De in de Delftse Hout getelde 'false positives' worden vaak veroorzaakt bij een lage windsnelheid (en dus een grotere kans op drijflagen) gecombineerd met een te langzaam opbreken en verdwijnen van de drijflaag. In het model was de drijflaag dan nog bezig te verdwijnen, terwijl in het veld geen drijflaag (meer) werd waargenomen.

Er zijn diverse algen-biomassa drempelwaarden uitgeprobeerd om het totale modelresultaat te verbeteren en om beter aan te sluiten bij de gebruikte categorie-indeling voor drijflagen. Een lage algen-biomassa drempelwaarde gaf gemiddeld een iets beter modelresultaat, maar wel ten koste van een groter aantal 'false positives'. Het totaalresultaat verbeterde in veel gevallen als alleen drijflaag-waarnemingen van categorie 2 of meer werden gebruikt.

De resultaten met het aangepaste model geven aan dat, in ieder geval voor de Delftse Hout, het model goed in staat is om de timing van het optreden van drijflagen te voorspellen (met een nauwkeurigheid van 85% voor drijflaag-categorie 1 of meer). Het model scoorde ook goed voor de timing van drijflagen in het Gooi- en Eemmeer op het beperkte aantal dagen dat er meetgegevens beschikbaar waren. In de Westeinderplassen was de modelscore rond de 50%, terwijl de Sloterplas met name slecht presteerde door de voorspelde lage algenbiomassa. Het modelresultaat veranderde slechts marginaal na aanpassing van het format voor windsnelheid en instraling en zijn daarom niet opgenomen in de nieuwe versie van het EWACS-drijflagenmodel.

De resultaten van de stand-alone EcoFuzz toepassing op de situatie in het jaar 2006 geven aan dat er meer en langer drijflagen van blauwalgen zijn opgetreden dan in 2008. Het model voorspelt volgens de veldgegevens vele drijflagen correct, al zijn de veldgegevens vrijwel alleen verzameld als er drijflagen optraden en kan dus geen goed beeld worden verkregen of in 2006 minder 'false positives' optreden.

In de Delftse Hout, met de meest complete set veldgegevens, is het aantal 'false positives' nog steeds hoog, maar dit resultaat lijkt op basis van de vele testen en simulaties die in 2007 en 2008 zijn uitgevoerd het best haalbare resultaat met deze veldgegevens en modelopzet.

Discussie en aanbevelingen voor de korte termijn (2009-2010)

Het EWACS-model is goed in staat om, althans voor de Delftse Hout, drijflagen te voorspellen die ook daadwerkelijk worden waargenomen in dagelijkse surveillance. Echter, het aantal 'false positives' (drijflaag wordt door het model voorspeld maar niet waargenomen in het veld) kon tijdens de calibratie en validatie niet voldoende worden verminderd. Het lijkt er op dat de modelopzet in zijn huidige vorm de grenzen heeft bereikt van wat kan worden gerealiseerd met de combinatie van fuzzy logic deterministische modellering en een slimmere wekelijkse reset van de algenbiomassa.

Omdat het primaire doel van een waarschuwingssysteem is om op tijd een voorspelling te genereren op mogelijke drijflagen van blauwalgen, is een tijdige drijflaag-waarschuwing met (te) veel 'false positives' mogelijk beter dan de methoden die waterbeheerders momenteel toepassen. Met andere woorden, hoe belangrijk zijn de 'false positives', zeker als een drijflaag-waarschuwing van het model door de waterbeheerders eerst op waarde wordt geschat voordat er een definitieve waarschuwing aan het (recreatie)publiek wordt gegeven. Op dit moment baseren de waterbeheerders waarschuwingen op (twee)wekelijkse monsters die moeten worden geanalyseerd, waardoor waarschuwingen óf te laat worden gegeven of te laat weer worden ingetrokken.

De zomer van 2008 was niet een echt goed blauwalgen-drijflagen-jaar door het instabiele weer en relatief korte perioden met rustig en warm weer met weinig wind. De stand-alone toepassing van EcoFuzz op de zomers van 2006 en 2008 geeft aan dat het model goed in staat is om een goed drijflagen-jaar te onderscheiden van een slecht drijflagen-jaar. De verwachting is daarom dat het model beter presteert in een jaar met omvangrijke en persistente drijflagen.

Het succes van een waarschuwingssysteem hangt niet alleen af van het model dat daarbij gebruikt wordt, maar ook van de kwaliteit van de gegevensverzameling en de aard van de veldgegevens die worden bepaald. Bij deze studie is voor de calibratie en validatie gebruik gemaakt van veldgegevens die in tijd en ruimte beperkt zijn ten opzichte van de variabiliteit in de vier proefgebieden. Zo gaf bemonstering van het Gooi- en Eemmeer met een meetboot en een vliegtuig *op dezelfde dag en tijd* op vele momenten een verschillend resultaat. In de Sloterplas werden een veel groter aantal categorie 2 drijflagen gesignaleerd dan in de overige proefgebieden, waarbij de diverse monsternemers afwijkende scores noteerden voor aan elkaar grenzende bemonsteringslocaties. Dit illustreert hoe complex monitoring is als een methode geheel is gebaseerd op een subjectieve indeling in categorieën. Daarnaast kunnen drijflagen van blauwalgen binnen korte tijd opkomen en weer verdwijnen, waardoor zo'n drijflaag heel gemakkelijk kan worden gemist als bemonsteraars op een vast moment van de dag een observatie doen.

Mede daarom zijn er, ondanks de grote inspanning die al is gedaan om de validatiegegevens te verzamelen, meer kwantitatieve veldgegevens nodig op een gedetailleerdere tijd- en ruimteschaal om een goede vergelijking van model en veldresultaten mogelijk te maken.

Tenslotte moet worden opgemerkt dat in de huidige modelopzet geen algenbiomassa wordt gemodelleerd. Het model wordt wekelijks gereset op basis van de beschikbare wekelijkse of tweewekelijkse waarnemingen op een beperkt aantal locaties in ieder proefgebied. Het is bekend dat de aanwezigheid en omvang van blauwalgen een zeer grote ruimtelijke spreiding heeft. Hoewel het model op de best mogelijke manier wordt gereset, zal het model om die reden waarschijnlijk niet de natuurlijke variatie in de werkelijke omstandigheden beschrijven. Deze methode zal de nauwkeurigheid van de voorspellingen niet ten goede komen. Aanbevolen wordt na te gaan welke invloed de ruimtelijke spreiding van de algenbiomassa heeft op het eindresultaat. Hetzelfde geldt voor de grootte (grid-size) van de rekencellen die het model gebruikt, en dan met name van de cellen langs de oever. Aanbevolen wordt om de grootte van de rekencellen flink te reduceren en na te gaan welke winst hiermee valt te halen.

Besloten is om in 2009 in te zetten op onderzoek naar de factoren die een correcte voorspelling belemmeren. Gerichte aanvullende kennis over de sleutelprocessen in drijflaagvorming is nodig om de kennisregels over de dynamiek van drijflagen te verbeteren. Daarbij zal ook worden nagegaan of het toepassen van deterministische in plaats van Fuzzy Logic kennisregels het EWACS-modelresultaat kan verbeteren.

Door het NIOO wordt in 2009 samen met de UvA experimenteel werk verricht gerelateerd aan het ontstaan en verdwijnen van drijflagen, waarbij de samenhang met turbulente menging voor verschillende groepen cyanobacteriën wordt beschouwd. In waterbassins van 2 m^3, waar licht, nutriënten en turbulentie ingesteld kunnen worden, zal worden getest onder welke omstandigheden drijflagen gevormd worden en weer verdwijnen. De kennis die daarmee wordt gegenereerd, zal na de zomer van 2009 in het model worden geïmplementeerd en getest op de datasets in de vier projectplassen. Ook in die zin is het dus gewenst dat we na de zwakke zomers van 2007 en 2008 in 2009 een mooie zomer tegemoet gaan.

Met uitzondering van de Delfse Hout wordt de monitoring in 2009 gecontinueerd, zodat er van de projectplassen (voor zover mogelijk op dagbasis) een complete dataset beschikbaar is over de drijflaagsituatie in 2009.

DE STOWA IN HET KORT

De Stichting Toegepast Onderzoek Waterbeheer, kortweg STOWA, is het onderzoeksplatform van Nederlandse waterbeheerders. Deelnemers zijn alle beheerders van grondwater en oppervlaktewater in landelijk en stedelijk gebied, beheerders van installaties voor de zuivering van huishoudelijk afralwater en beheerders van waterkeringen. Dat zijn alle waterschappen, hoogheemraadschappen en zuiveringsschappen en de provincies.

De waterbeheerders gebruiken de STOWA voor het realiseren van toegepast technisch, natuurwetenschappelijk, bestuurlijk juridisch en sociaal-wetenschappelijk onderzoek dat voor hen van gemeenschappelijk belang is. Onderzoeksprogramma's komen tot stand op basis van inventarisaties van de behoefte bij de deelnemers. Onderzoekssuggesties van derden, zoals kennisinstituten en adviesbureaus. zijn van harte welkom. Deze suggesties toetst de STOWA aan de behoeften van de deelnemers.

De STOWA verricht zelf geen onderzoek, maar laat dit uitvoeren door gespecialiseerde instanties. De onderzoeken worden begeleid door begeleidingscommissies. Deze zijn samengesteld uit medewerkers van de deelnemers, zonodig aangevuld met andere deskundigen.

Het geld voor onderzoek, ontwikkeling, informatie en diensten brengen de deelnemers samen bijeen. Momenteel bedraagt het jaarlijkse budget zo'n zes miljoen euro.

U kunt de STOWA bereiken op telefoonnummer: 030 -2321199.
Ons adres luidt: STOWA, Postbus 8090, 3503 RB Utrecht.
Email: stowa@stowa.nl.

Website: www.stowa.nl

VOORSPELLINGSSYSTEEM DRIJFLAGEN VAN BLAUWALGEN

RESULTATEN PILOTS 2008

CONTENTS

1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Cyanobacterial (blue-green algae) surface scums represent a major problem in many recreational lakes in The Netherlands, especially during the summer period when cyanobacterial growth rates are high and cells may become highly buoyant leading to the formation of large scums on the water surface during periods of stable weather conditions. As a result of transport by light winds, cyanobacterial scums often accumulate along lake shorelines, where potential impacts on recreational users are greatest.

Cyanobacterial scums have many negative effects on lake water quality and the overall recreational and aesthetic value of aquatic systems. These may include loss of water clarity, the presence of large unsightly green scums, deoxygenation and strong odours. Many species of cyanobacteria also have the ability to produce natural, intracellular toxins, which may have implications for human health, particularly for recreational users coming in direct contact with the affected water such as swimmers. Toxin concentrations may increase by several orders of magnitude in a matter of just a few hours associated with the sudden increase in cyanobacterial biomass in the surface waters.

In order to manage lake water quality and minimise potential health risks associated with the cyanobacterial blooms for recreational users, water managers carry out routine water sampling over the summer period when the development of surface scums is most likely to occur. As part of the European Bathing Water Directive, water samples are generally collected fortnightly although cyanobacteria cell counts and toxin analysis are currently not a mandatory part of the analyses. Should large cyanobacterial scums be present, official warnings or closures are issued for the affected water body and beaches.

Cyanobacterial surface bloom formation is a highly dynamic process and cells have the ability to form a surface bloom over the course of only a few hours. Traditional sampling, especially over the fortnightly time scales as is currently carried out, is not sufficient to detect all possible surface blooms due to the limited sampling frequency and limited spatial resolution of the monitoring sites. Routine sampling on a more regular basis and at a greater spatial resolution for all lakes is not feasible and may still not capture all blooms present.

The ability to automatically forecast the timing and location of a surface cyanobacterial scum several days in advance would allow water managers to make better decisions to potentially mitigate scum transport into recreational zones, and better inform recreational users about potential health risks over the coming days. As the formation and development of cyanobacterial scums is a complex and dynamic process, scums cannot be easily predicted based on routine water quality monitoring alone. Complex water quality models may offer insights into the timing and development of bloom events in the system as a whole, but require much site-specific data for parameterisation and calibration purposes.

In the late 1990's WL l Delft Hydraulics collaborated with RIZA to develop the model Eco-Fuzz (Ibelings et al, 2003), used to predict the appearance and disappearance of cyanobacterial surface blooms based on fuzzy logic modelling. Fuzzy logic was used to describe three governing conditions for surface bloom formation: (1) presence of existing cyanobacterial population (2) cell buoyancy and (3) water column stability. The model was applied to Lake IJssel, coupled with the water quality model Delwaq-BLOOM-Switch to estimate phytoplankton biomass. The model results were then compared with 12 years of NOAA-AVHRR (National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometers) satellite images for validation.

The EcoFuzz model showed very promising results with existing surface blooms in Lake IJssel predicted with a high degree of accuracy (Ibelings et al, 2003). However, it was unknown how well the model can simulate surface blooms in much smaller lakes in the Netherlands. The existing EcoFuzz model simulations also did not include simulations of shoreline scums, and was focused rather on the open waters of the lake where actual surface blooms were predicted only 5.4% of the time. Surface scums may be expected to represent a greater problem on the shoreline of a water body, due to higher rates of cell accumulation associated with light wind transport of scums from the open waters. The shoreline of a water body is also more likely to be sheltered from the wind, and scums may persist longer in a more stable water column. Finally, the water quality model used in the study of Ibelings (2003) to calculate cyanobacterial biomass did not fully include vertical migration of cyanobacteria through buoyancy, which may affect the accuracy of the phytoplankton biomass calculations. Horizontal transport was incorporated as part of the existing EcoFuzz study, however, after scums were dispersed through wind action, scum biomass was not added back to the local population.

The ultimate aim of this research was to develop a fully operational, stand-alone early warning system for forecasting cyanobacterial surface scums in both small and large lake systems a few days to a week in advance. The system must be able to predict not only when surface scums develop, but also where the scums will occur, for example the shoreline location where risks of contact with the bloom are greatest for recreational users. This is of primary importance for meeting the future requirements of the European Commission's Bathing Water Directive, where minimising cyanobacterial exposure to recreational users and the potential use of a warning system is of primary importance. The final product must be easy to apply to different lake systems, with minimal input data and model recalibration, yet be highly reliable with an accurate forecast relative to what is actually observed in the lake. It is intended that the model must autonomously generate warnings on basis of the long-term weather forecast, for up to seven days in advance.

The complete system, once incorporated into an operational warning system as part of a future study, will become an important management tool for various users. This may include users at a Provincial level for issuing official lake warnings and closures and for communicating risks to the public, and users at a lake management level (Water Boards) to prevent or minimise potential risks through the early implementation of management strategies, for example the automated activation of artificial mixing systems during scum-favourable conditions to prevent scum formation.

The overall research project is being conducted in two phases. Phase 1, which was partly carried out in 2007, includes development of model processes to simulate cyanobacterial scum appearance, transport and disappearance, as well as the implementation and calibration of the model instrumentation. Phase 2 of the overall project examines the applicability of the model as a fully operational system through the simplification of model input data streams, automation of the model simulations in a forecasting mode, and interpretation of the model results and generation of warnings to end users.

1.2 PREVIOUS RESEARCH ACTIVITIES

In 2007 Deltares partially conducted Phase 1 of the project which included (1) the initial model code development to integrate the existing EcoFuzz model into Delft3D-FLOW, Delwaq and BLOOM II, (2) calibration and testing of the complete model instrumentation on four test locations based on fortnightly reset periods, (3) validation of model output in respect to the timing and locality of scum formation on the basis of daily field data, and (4) further model code developments, testing and validation to improve model scores relative to the available field data (see Deltares, 2008).

The 2007 summer did not represent a "good" year for cyanobacterial scums due to highly unstable weather patterns and limited periods of warm, calm, low wind conditions. Cyanobacterial scums were considered to be mostly absent in many lake systems compared to previous years, and there was a general lack of field validation data available for both scum presence and absence to fully validate the advances made with the model setup. For all lake systems where the model instrument was tested, a large number of false positive (scum present in model but not in field) events were predicted by the model, but due to the overall model complexity coupled with the limited number of field scum events available for calibration in 2007 it was difficult to advance the model further in the absence of better field validation data.

While a number of advances were made with the model setup in the 2007 study, the model was never fully tested in an operational setting and cyanobacterial scum 'forecasts' were only generated by the model as hind casts after the end of the 2007 summer period.

1.3 RESEARCH ACTIVITIES THIS STUDY

The objectives of the current study were to build on the progress made with model development and implementation in 2007 (Deltares, 2008), with particular focus on further model testing in an operational (forecasting) environment. The current research was comprised of three main objectives:

1. Operational testing of the current (2007) model instrumentation, including data delivery, model input data, forecasting of cyanobacterial scums and delivery of the model simulation results, through weekly model forecasts. The main focus of this objective was to determine the feasibility of the model in an operational context in terms of data streams, data protocols and effective communication of the model output, together leading to a timely algal scum warning;
2. Validation of the current model instrumentation through comparisons with the available field data to determine model accuracy using both forecast and hind cast model data input;
3. Further calibration of the current model instrumentation to improve overall model performance, including a more detailed examination of model input data, processes and interpretation of model output.

1.4 PROJECT ORGANISATION

The research conducted in the current study was commissioned by STOWA, on behalf of the four Water Boards who also participated in the 2007 research program: Hoogheemraadschap van Delfland, Hoogheemraadschap van Rijnland, Waternet and Rijkswaterstaat

IJsselmeergebied. As in 2007, representatives from each water board formed an integral part of the research team in the current study through the setup and management of the field sampling programs required to run the model instrumentation for each of four study lakes, as well as through participation in regular meetings held to assess and further improve the model setup and application. The research committee members representing the Water Boards, STOWA as well as NIOO were:

- Jasper Stroom (Waternet, Team Co-ordinator)
- Wil van der Ende (Hoogheemraadschap van Delfland)
- Johan Oosterbaan (Hoogheemraadschap van Rijnland)
- Jeroen Postema and Tineke Burger (Rijkswaterstaat IJsselmeergebied)
- Michelle Talsma (STOWA)
- Wolf Mooij (NIOO)

In the early stages of the study, Imke Leenen assisted with the field sampling program for Westeinderplassen on behalf of Hoogheemraadschap van Rijnland. Model development, implementation, operational testing, calibration and analysis were conducted by Deltares, including David Burger (implementation), Simon Groot (project management), Hans Los (phytoplankton), Rolf Hulsbergen and Arjen Markus (model code development, programming and testing) and Matthijs Lemans (assistance with bulletins). Bas Ibelings (NIOO, specialist cyanobacteria and Fuzzy logic modelling) provided scientific input over the duration of the project.

1.5 INTRODUCTION FOUR STUDY LAKES

The same four study lakes (Delftse Hout, Gooimeer-Eemmeer, Sloterplas and Westeinderplassen) examined in 2008 were again selected in the current study to conduct model simulation trials with the complete cyanobacterial bloom forecasting instrument. All four lakes are important for recreational activities, and feature frequent cyanobacterial surface blooms over the summer months. The lakes vary in size, depth and complexity to allow better testing and validation of the complete model instrumentation over a wider variety of systems.

1.5.1 DELFTSE HOUT

The Delftse Hout is a small (area 0.5 km^2), shallow (maximum depth 3 m) lake situated northwest of Delft. Management of the lake falls under the jurisdiction of Hoogheemraadschap van Delfland. The lake has no surface inflows, apart from overland runoff from a catchment primarily made up of recreational parkland. Delftse Hout is an important recreational lake, popular with swimmers over the summer period. Cyanobacterial blooms are frequent over this time, occasionally leading to the closure of the lake. There have been no detailed studies on the water quality of this lake, apart from routine sampling for nutrient and chlorophyll-a concentrations.

1.5.2 GOOIMEER AND EEMMEER

The Gooimeer (area 17.6 km^2) and Eemmeer (area 13.7 km^2) are two interconnected lakes adjacent to Lakes Nuldernauw and IJmeer. Both lakes have a long history of eutrophication, due to high external nutrient loads associated with intensive agricultural developments. Although water column nutrient concentrations continue to decline following significant reductions in external loads, cyanobacterial scums still frequently occur during summer months, particularly in the Gooimeer. High cyanobacterial biomass typically accumulates in areas along the northern shoreline of the Gooimeer, for example in the Almere yacht harbour and the recreational swimming beach Almere strand harbour. The phytoplankton community of the lake as a whole is not well documented, although summer cyanobacterial blooms are dominated by *Microcystis* and *Planktothrix* species.

1.5.3 SLOTERPLAS

The Sloterplas is a small (area 1 km^2) yet deep (mean depth 15 m) sand mining lake situated in a predominantly urban catchment west of Amsterdam. External nutrient loads to the lake are high, and cyanobacterial blooms now occur frequently over the summer period, with scums persisting in a small harbour in the north part of the lake as well as the recreational swimming beaches on the north eastern shoreline. There is little information available on the water quality and phytoplankton community of the lake, although summer cyanobacteria species are dominated by *Planktothrix* and *Microcystis* species. The lake is managed by Waternet.

1.5.4 WESTEINDERPLASSEN

The Westeinderplassen is a shallow (mean depth 2.8 m) lake with a surface area of 8.5 km^2. The lake morphology is complex, particularly in the northern reaches of the lake (Kleine Poel) which is made up of a series of small embayments featuring many islands and much urban development. The Kleine Poel is connected to the main basin of the lake (Grote Poel) via a series of small canals. The lake is directly connected to a large surface canal (Ringvaart), used to control the lakes water level. Cyanobacterial surface blooms occur almost annually in the lake each summer, dominated by *Microcystis* and *Anabaena* species. The scums are particular persistent around the northern shorelines of the main lake basin, as well as in the smaller urban basins. Management of the Westeinderplassen falls under the jurisdiction of Hoogheemraadschap van Rijnland. There has been no previous water quality modelling studies on this lake.

1.6 REPORT OVERVIEW

This report is comprised of six chapters. Chapter 1 provides a general introduction to the study, and presents the study aims, objectives and general research activities (see above). The model instrumentation including model setup and key processes represented in the model to forecast scum events is introduced in Chapter 2, while Chapter 3 discusses the operational testing of the model tool over the 2008 summer period. In Chapter 4, the results of the model forecasts are validated through comparisons with the available field data and in Chapter 5 further improvements and testing of the model is examined. The study conclusions and recommendations for further research are discussed in Chapter 6.

The results of a workshop held in September 2009 between a number of cyanobacterial experts in the Netherlands to present the EWACS study and gain new ideas for model improvements are provided in Appendix A.

2

MODEL SETUP AND DEVELOPMENT

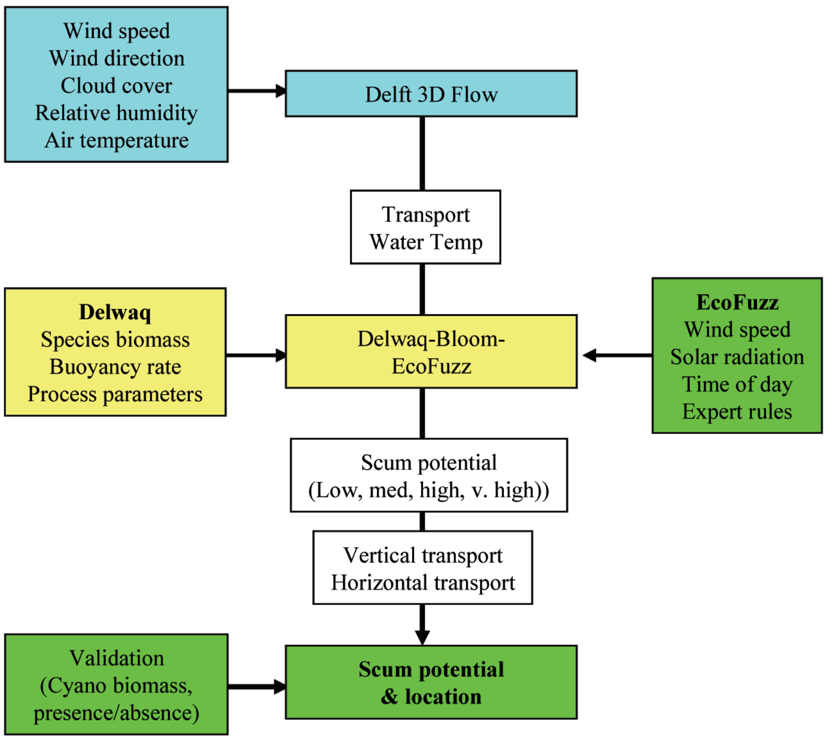
2.1 MODEL INTRODUCTION

In this chapter the setup of the complete cyanobacterial scum early warning instrument is introduced, based on the model code developments conducted in Phase 1 of the study in 2007 (see Deltares, 2008).

The complete model tool for forecasting cyanobacterial scums is based on three models (Fig. 2.1):

1 a hydrodynamic model to simulate vertical and horizontal water velocities (model Delft3D-FLOW);
2 a fuzzy logic model to simulate cyanobacterial scum appearance and disappearance potential using fuzzy logic (model EcoFuzz within Delwaq process library);
3 a water quality model (Delft3D-ECO) to simulate cyanobacterial scum processes, including buoyancy, surface accumulation and horizontal transport routines, to provide simulations of scum presence and absence. Buoyancy is triggered in Delwaq based on output from EcoFuzz, and is based on negative sedimentation velocities for each species.

FIGURE 2.1 SCHEMATISATION OF THE COMPLETE CYANOBACTERIAL EARLY WARNING INSTRUMENT, INCLUDING DATA INPUTS TO THE HYDRODYNAMIC MODEL (DELFT3D-FLOW, HIGHLIGHTED IN BLUE), SCUM APPEARANCE AND DISAPPEARANCE MODEL (ECOFUZZ WITHIN DELWAQ, HIGHLIGHTED IN GREEN) AND WATER QUALITY MODEL (DELWAQ-BLOOM, HIGHLIGHTED IN YELLOW)



2.2 HYDRODYNAMIC MODEL

The accumulation of cyanobacterial surface scums along the shoreline of a water body is dependent on both vertical and horizontal transport, driven predominantly by meteorological conditions including wind speed and wind direction. In this study the three-dimensional hydrodynamic and transport simulation model Delft3D-FLOW (see WL | Delft Hydraulics, 2006) is used to calculate non-steady flow and transportation resulting from meteorological forcing data on a curvilinear, boundary-fitted grid. The results of the hydrodynamic simulations, including water velocities, are used as direct input to the water quality and ecological model Delft3D-Eco to simulate the transportation of water quality substances. Both models utilise the same computational grid, including the horizontal and vertical grid structure and bathymetry.

2.2.1 GRID CONSTRUCTION

In Phase 1 of the study (Deltares, 2008) Hydrodynamic grids were created for each lake based on the land boundary files provided by each water board. The land boundary files used to create a model grid for each of the four study lakes were supplied in GIS format by the relevant Water Board (Delftse Hout, Sloterplas, Westeinderplassen), or obtained from a previous modelling application conducted in 2009 (Deltares 2008, Gooimeer-Eemmeer). The land boundaries for all four lakes were compared with satellite images derived from Google Earth™ to ensure accuracy and that the key shoreline features were represented in the model boundary. A semi-curvilinear grid construction was applied to ensure that the grid boundaries closely matched the land boundary, thereby avoiding a stair-case like schematisation and providing the most detail along the shorelines which represent the area of greatest interest for monitoring scum accumulation in this study. A series of dry cells and thin dams were applied to each grid, where necessary, using satellite and aerial photographs to better represent the shoreline and key features such as islands and harbour entrances.

Model simulation times are largely governed by the total number of grid cells represented in the model. The overall aim of this study was to develop an early warning system for algal scums and relatively short model run times (< 1 hour) are therefore of primary importance when developing such a system. In Phase 1 of the study it was initially chosen to limit the grid resolution to a maximum of 1000 cells per layer, and a total of 5000 grid cells in the whole model application for each of the four pilot lakes. In the new study the model grids for the Gooimeer and Eemmeer were refined to better represent the resolution around the Almere Harbour. The grid was also refined for the Westeinderplassen to better represent the islands and small channels in the northern regions of the lake.

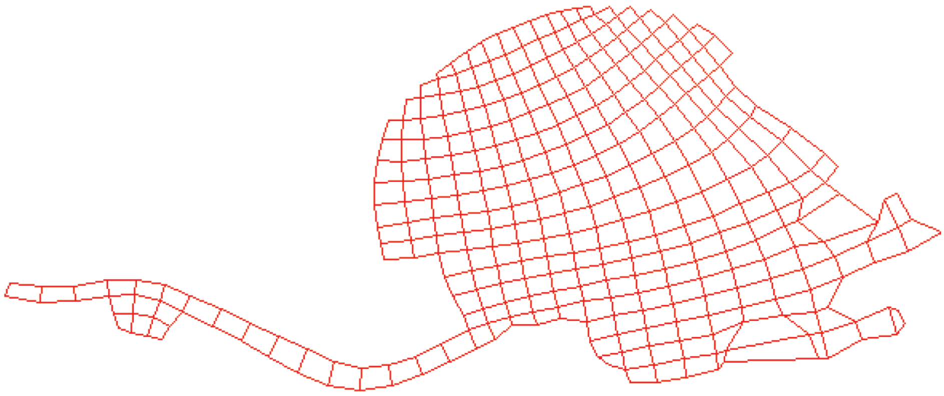
The final mean grid resolution for each of the four lakes is provided in Table 2.1 and the final grid schematisation in Figures 2.2 – 2.4.

TABLE 2.1 SUMMARY OF GRID SCHEMATISATION FOR THE FOUR STUDY LAKES

Lake	Lake area (km^2)	Grid size (m)	Depth layers	Total cells
Delftse Hout	0.2	28	6	1327
Gooimeer - Eemmeer	30	150	8	17418
Sloterplas	1	27	11	13174
Westeinderplassen	8.5	50	8	34561

For all four lakes, a z layer vertical grid construction was applied, and the amount of layers were varied between 6 (Delftse Hout) and 11 (Sloterplas) (Table 4.1). The upper surface layer was kept reasonably fine (0.1 m), with layer thickness increasing by no more than 35% with increasing depth.

A



B

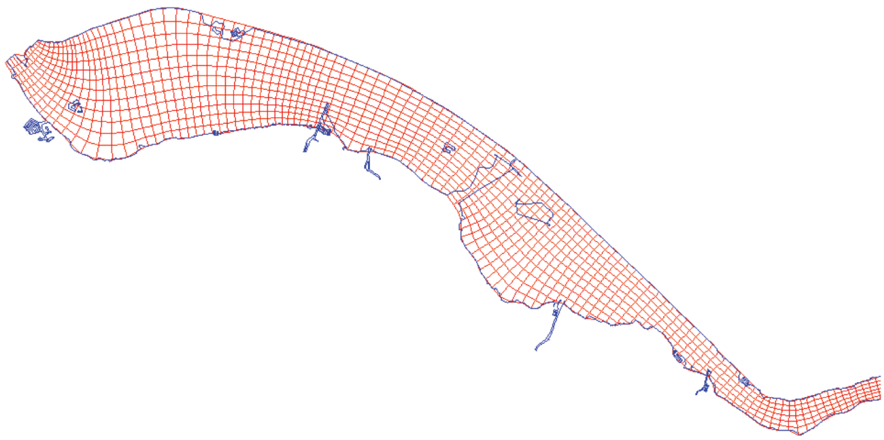


FIGURE 2.2 HYDRODYNAMIC GRID SCHEMATISATION FOR (A) DELFTSE HOUT AND (B) THE EXISTING GRID FOR GOOIMEER-EEMMEER

FIGURE 2.3 HYDRODYNAMIC GRID SCHEMATISATION FOR LAKE GOOIMEER FOR (A) THE EXISTING MODEL (DELTARES, 2008) AND (B) THE REVISED MODEL WITH MORE RESOLUTION AROUND THE ALMERE HARBOUR AREA

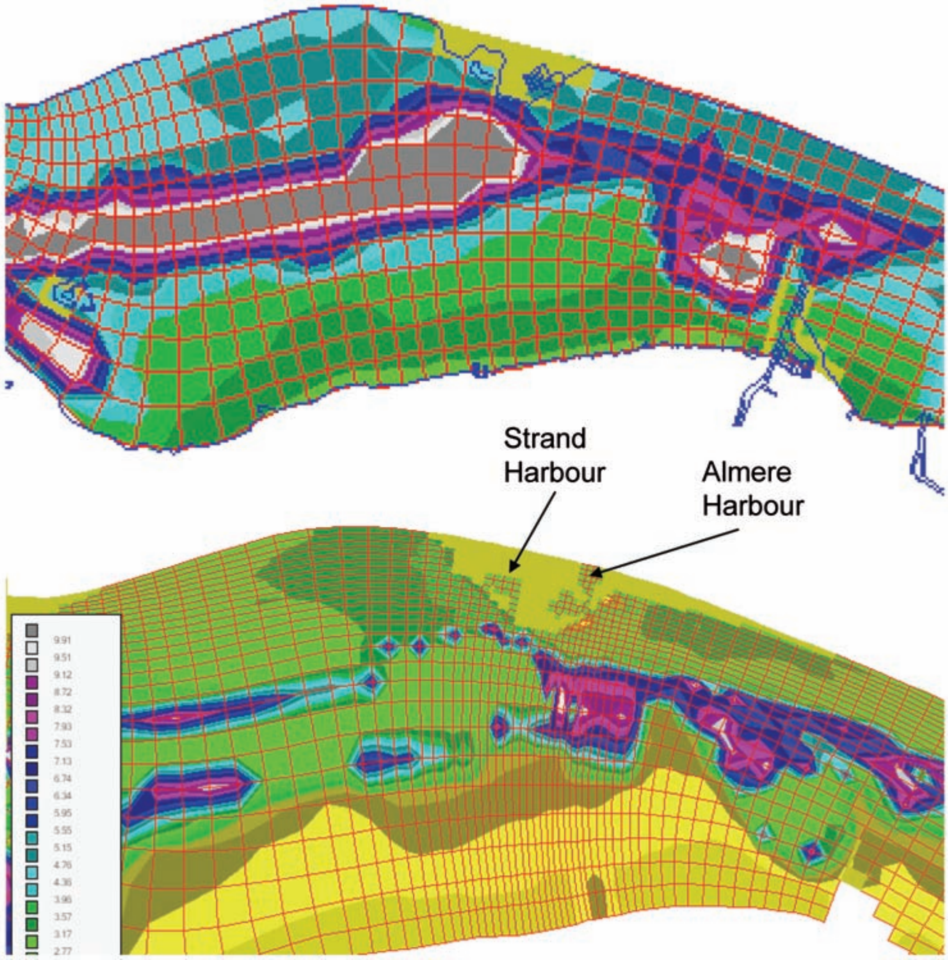


FIGURE 2.4 HYDRODYNAMIC GRID SCHEMATISATION FOR SLOTERPLAS

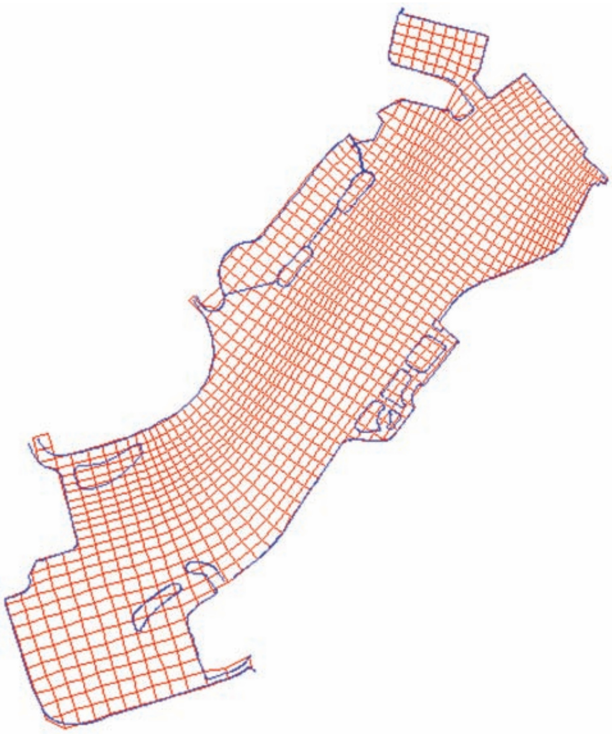


FIGURE 2.5 HYDRODYNAMIC GRID SCHEMATISATION FOR WESTEINDERPLASSEN

2.2.2 BATHYMETRY

Bathymetry data for each lake were provided by the corresponding Water Board, with linear interpolation used to fill missing grid cell depths from the measured data. For Gooimeer - Eemmeer, which has a mean depth of 2 m but features some deep pits of up to 30 m in depth, it was assumed that the deep zones do not play a major role in regulating phytoplankton scums due to their relatively small water volume. Accordingly a maximum depth of 10 m was specified in the model. For Sloterplas, which has a mean depth of 15 m, it was assumed that the surface mixed layer (< 10 m) is most important for phytoplankton development and in the absence of detailed temperature profiles to calibrate the flow model, a maximum depth of 10 m was also specified for this lake. The bathymetry used for each lake is shown in Figures 2.6 – 2.7.

2.2.3 FLOW BOUNDARIES

Due to the lack of available flow data and the intention to keep the overall algal scum warning tool as simple as possible, flow boundaries such as surface and sub-surface inflows and outflows were not modelled in this study. Due to the shallow nature of the lakes, wind transport is likely to be the dominant transport mechanism and the exclusion of surface inflows and outflows from the model is therefore not likely to have a significant influence on the flow simulation results.

2.2.4 ADDITIONAL PARAMETERS AND PROCESSES

Mean hourly wind speed and direction were obtained either from Schiphol Airport (for Gooimeer-Eemmeer, Sloterplas, Westeinderplassen) or Rotterdam Airport (Delftse Hout), and applied uniformly as input to the model. A wind velocity dependent wind drag coefficient was applied in the model (Smith and Banke, 1975), reflecting increases in surface roughness associated with increasing wind velocities.

Heat exchange was modelled using the Proctor Heat flux model, which calculates effective back radiation and heat losses due to evaporation and convection. Mean hourly air temperature, relative humidity and percent cloud cover were used as input to the model, derived either from Schiphol Airport (for Gooimeer-Eemmeer, Sloterplas, Westeinderplassen) or Rotterdam Airport (Delftse Hout).

Bottom roughness was specified in the model as a constant and uniform value over the whole surface area, based on a Chézy roughness formula and a coefficient of 65, which translates to a very smooth bottom. An initial uniform water column temperature was specified for the start date of the model, based on the most recently available field measurement for each lake. The initial water column level was specified at 0 m.

Flow model simulations were carried out for all four lakes using a time step of 1 minute with hourly model output.

FIGURE 2.6 HYDRODYNAMIC MODEL BATHYMETRY FOR (A) DELFTSE HOUT AND (B) GOOIMEER-EEMMEER

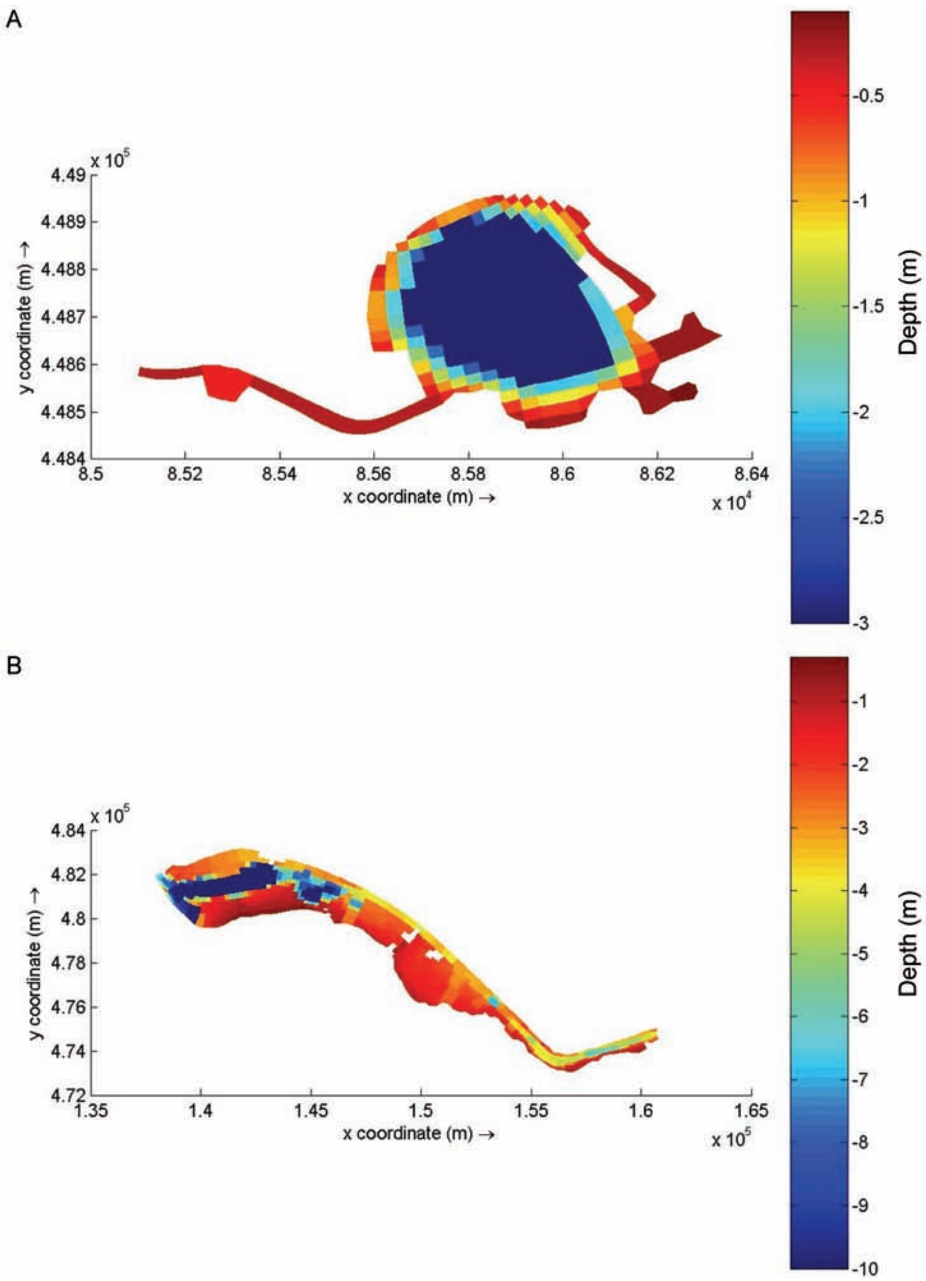
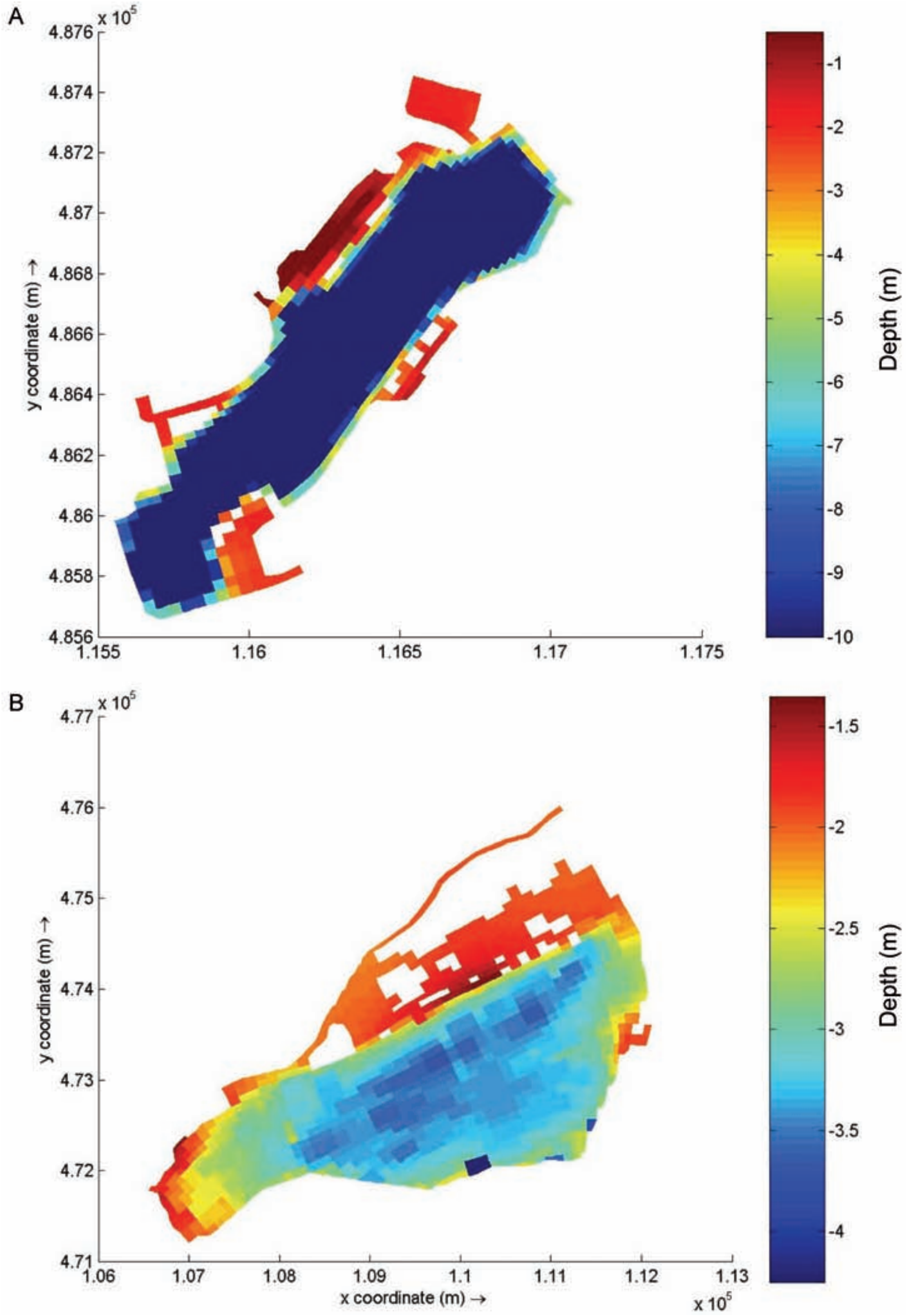


FIGURE 2.7 HYDRODYNAMIC MODEL BATHYMETRY FOR (A) SLOTERPLAS AND (B) WESTEINDERPLASSEN



2.3 FUZZY LOGIC MODEL

The model EcoFuzz, developed by WL | Delft Hydraulics in collaboration with RIZA in the late 1990's, is used to determine the likelihood of cyanobacterial surface scum appearance and disappearance based on fuzzy logic modelling (see Ibelings et al, 2003). The fuzzy logic model was developed to replace the uncertainties and difficulties associated with modelling surface bloom formation and disappearance deterministically. EcoFuzz only simulates scum appearance and disappearance potential, and not cyanobacterial biomass or surface scum transportation.

EcoFuzz uses two steps of logical (fuzzy) inference to make a qualitative prediction on the degree of cyanobacterial surface bloom appearance (Fig. 2.8). Water column stability and cell buoyancy are inferred from wind speed, time of day and irradiance, which in turn infers surface bloom appearance. Scum disappearance in turn also inferred from wind velocity, as well as irradiance. In 2007 the existing stand EcoFuzz alone model was integrated into the Delwaq process library to allow the model to be sun simultaneously with the water quality model, with output of scum appearance and disappearance used as input to the Delft3D-ECO routines for cyanobacterial scum formation, transportation and disappearance.

For all basis simulations conducted in the current study, the membership functions used in EcoFuzz to determine the appearance and disappearance of surface cyanobacterial blooms were derived directly from the existing simulations of the IJsselmeer (Ibelings et al., 2003) (Fig. 2.9). Three parameters were used as input to the EcoFuzz model;

- Time of day (hr);
- Mean hourly wind speed (m s^{-1}), and;
- Total irradiance for the previous 6 hours (J cm $^{-2}$).

The time of day was derived directly from the Delwaq model time step while mean hourly wind speed and irradiance are derived forecasted or observed meteorological data.

FIGURE 2.8 LOGICAL INFERENCE USED TO PREDICT SCUM APPEARANCE AND DISAPPEARANCE IN THE FUZZY LOGIC MODEL ECOFUZZ. THE WIND VELOCITY SCALES USED FOR THE SCUM APPEARANCE AND SCUM DISAPPEARANCE VARY

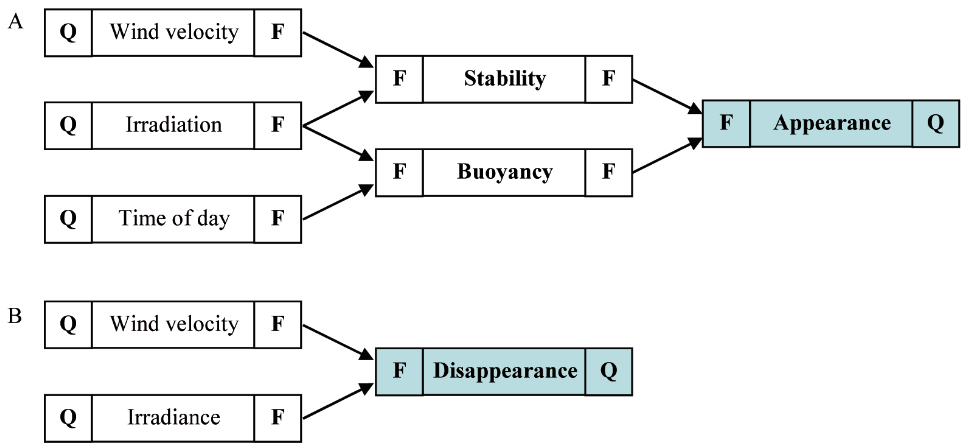
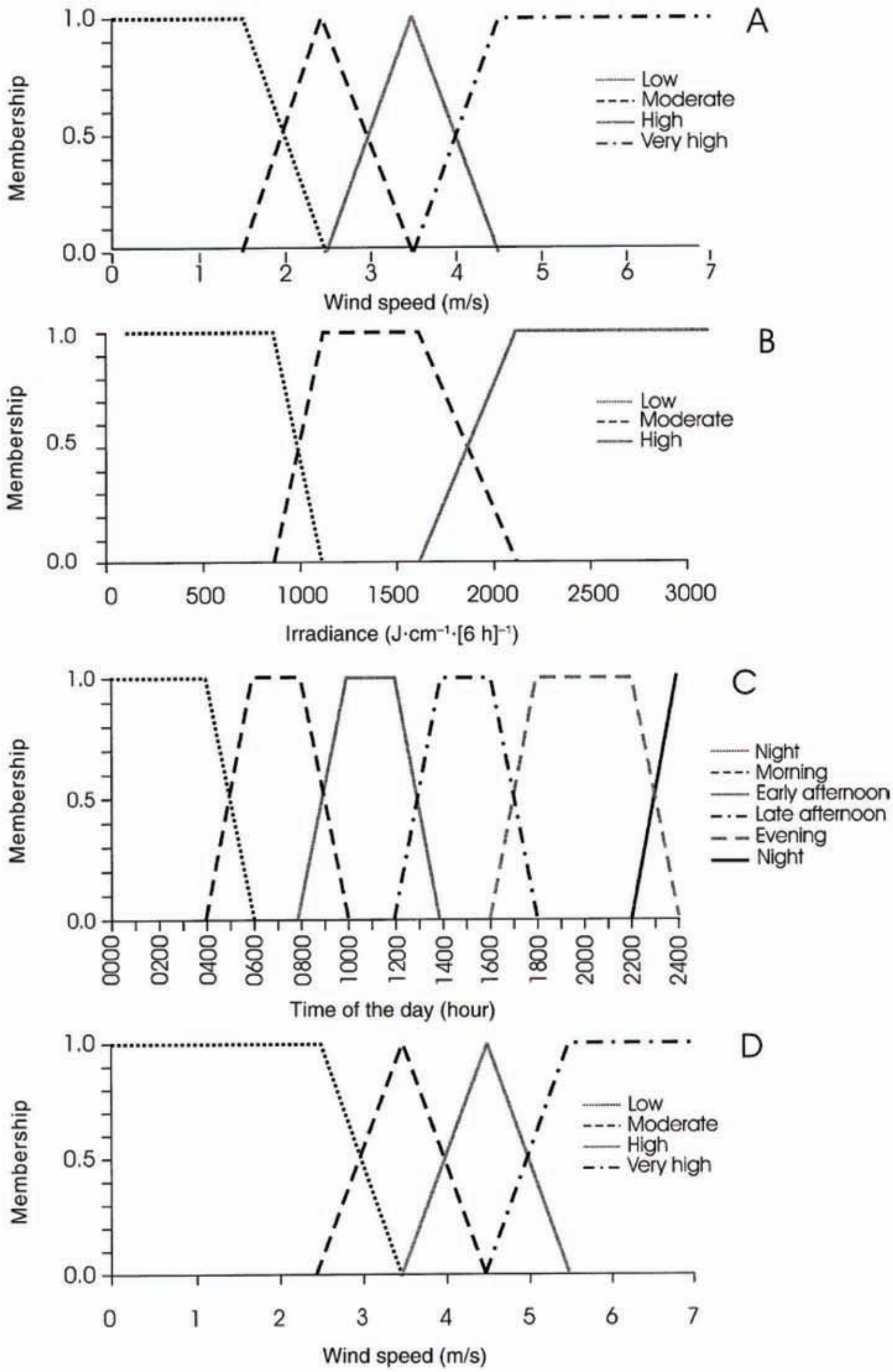


FIGURE 2.9 MEMBERSHIP FUNCTIONS USED BY ECOFUZZ TO DETERMINE APPEARANCE OF SURFACE BLOOMS: (A) MEAN HOURLY WIND SPEED, (B) CUMULATIVE IRRADIANCE FLUX OVER THE PAST 6 HOURS, (C) TIME OF DAY AND (D) MEAN HOURLY WIND SPEED FOR GOVERNING SURFACE BLOOM DISAPPEARANCE (FROM IBELINGS ET AL., 2003)



2.4 WATER QUALITY MODEL

The three dimensional water quality model Delft3D-ECO is applied in the complete cyanobacterial scum forecasting instrument to simulate cyanobacterial buoyancy, scum formation and scum transport, based on scum appearance and disappearance potential simulated by the model EcoFuzz. The water quality model is based on the Delwaq (DELft WAter Quality) process library, which can be utilised for a wide range of water quality applications in both freshwater and marine environments. Phytoplankton primary productivity is simulated within Delft3D-ECO using the coupled model BLOOM II. In Phase 1 of this study (Deltares, 2008) a number of new processes and routines were developed within the Delwaq process library to allow cyanobacterial scums to be simulated by the model, including:

- a new buoyancy process to model cyanobacterial buoyancy based on appearance and disappearance predictions from EcoFuzz,
- the expansion of the total number of phytoplankton species represented in the model to accommodate for scum algae,
- a new scum formation processes to model the creation and disappearance of scum algae,
- new model processes for surface bloom horizontal transport, including implementation of wind drag coefficient and grid-cell specific wind scaling factor to reflect localised differences in wind speed.

2.4.1 HYDRODYNAMIC INPUTS

The results of the hydrodynamic simulations, including water velocities, water level and vertical eddy diffusivities and viscosities were used as direct input to Delwaq. Water column temperature, calculated by the flow model, was also imported. Horizontal or vertical aggregation of the grid cells were not used, therefore the grid structure used by Delft-Eco was identical to that in Delft3D-FLOW.

2.4.2 PHYTOPLANKTON MODELLING

The most important water quality processes determining phytoplankton primary productivity are nutrient cycling and light availability. Based on results of the first trials with the complete model instrumentation conducted in 2007 (Deltares 2008), it was apparent that despite many attempts at various calibrations, it is not possible to model the phytoplankton community accurately in the absence of a detailed nutrient balance for each lake, and under the constant reset regime applied with every new forecast simulation. Inaccurate water column nutrient concentrations always led to a change in species dominance and unrealistic cyanobacterial growth rates in all four study lakes. While the model simulations of scum appearance and horizontal bloom transport indicated that these processes were working well, the overall modelling tool could not be calibrated with the unrealistic projections of phytoplankton biomass. In order to improve the phytoplankton biomass simulations, changes were made in the modelling approach, with the phytoplankton model BLOOM simplified to prevent sudden changes in species composition in response to the inaccurate water column nutrient simulations. This was first tested as part of the 2007 study and was considered more successful than full biomass simulations, and was therefore again applied in the present study.

In the revised modelling approach the phytoplankton biomass were simulated through simplification of the setup of the primary production model BLOOM as follows:

- Phytoplankton growth rates were set to zero for all species and types, so that growth would not occur;
- Phytoplankton mortality and respiration rates were set to zero, so that in the absence of growth, phytoplankton biomass would not decrease. Under this scenario regular biomass measurements are highly important to force the model as further changes in biomass over the simulation period are not modelled;
- Sedimentation rates for all species were also set to zero;
- Phytoplankton biomass were reset weekly in the model in the current study instead of bi-weekly, as applied in the existing study in 2007 (Deltares, 2008).

In this approach water column nutrients are not important, nor are other processes such as dissolved oxygen dynamics, light availability and resuspension.

2.4.3 PHYTOPLANKTON SCUM FORMATION PROCESSES

Three phytoplankton taxonomic groups were simulated in the model; cyanobacteria, chlorophytes and diatoms. Cyanobacteria, the main focus of the study, were simulated to genus level while chlorophytes and diatoms were only simulated generally. For cyanobacteria, three genera were specified based on those most observed to have high biomass and form nuisance blooms in the four study lakes. These were *Microcystis*, *Aphanizomenon* and *Planktothrix*.

EcoFuzz output to Delwaq model

A number of thresholds are implemented in Delwaq to translate the scum appearance potential derived from EcoFuzz to the scum buoyancy and surface bloom formation routines in the water quality model (Fig. 2.10). EcoFuzz calculates the likelihood of scum formation based only on physical factors, and not the starting biomass of cyanobacteria. Cyanobacterial biomass may also be an important factor determining surface bloom formation as surface scum formation can be dependent on the number of cyanobacterial cells present in the water column. A cyanobacteria biomass threshold is therefore implemented as a Delwaq process parameter (CrCyano) to allow the concentration over which surface scums could form to be specified. Although the cyanobacteria threshold is the most accurate biomass indicator for governing bloom formation in this study, a total chlorophyll-a threshold can also be used in the model (CrChlfa). A switch (SwEcoThres) in the Delwaq process list can be used to alternate between the cyanobacteria biomass threshold (value = 2) or chlorophyll-a threshold (value = 1). This threshold is expressed as μg Chl-a L^{-1} and any value can be specified in the model. In this application all thresholds were set to zero.

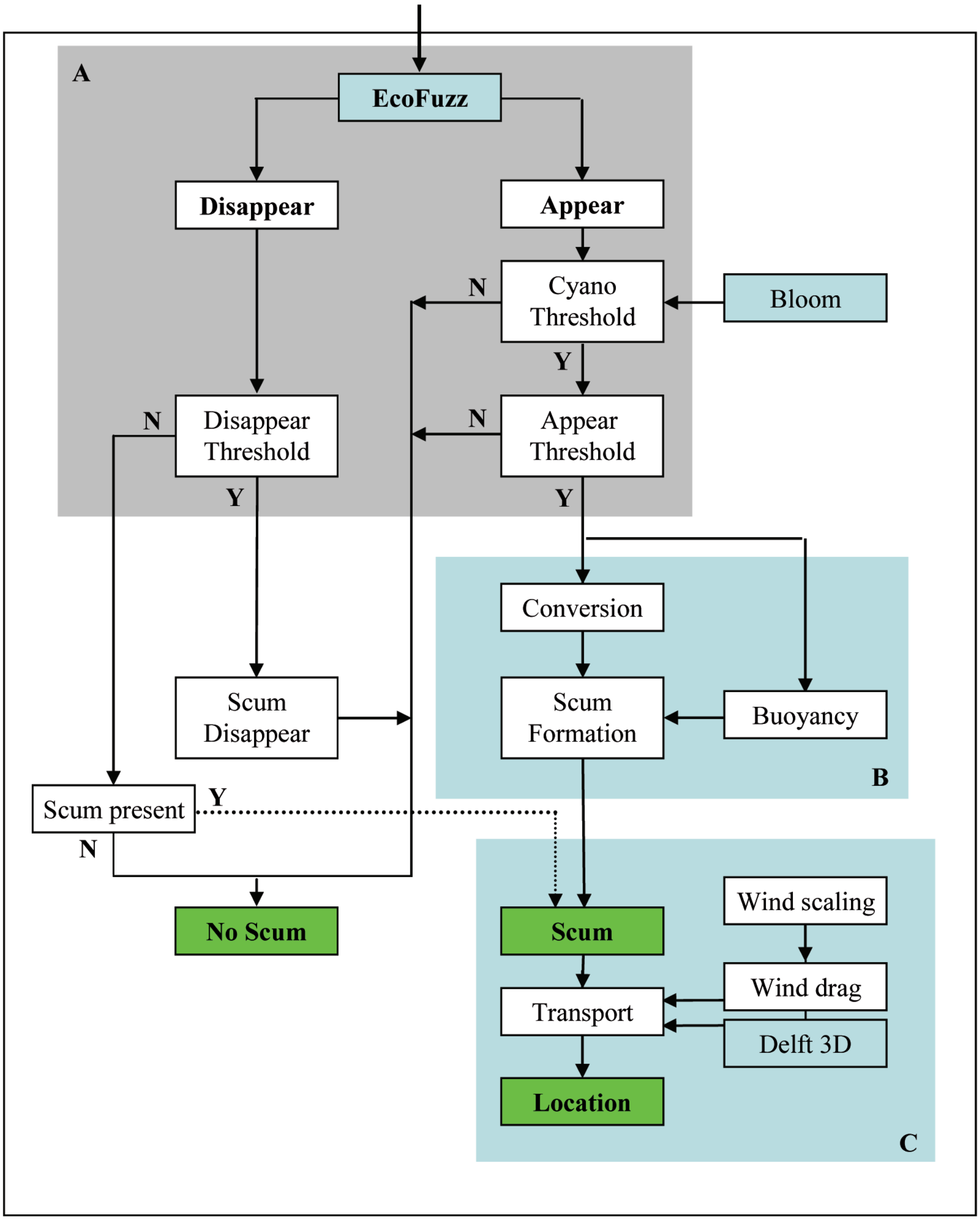
If the total cyanobacteria biomass in a given time step exceeds the specified threshold value, a second threshold value is used to determine if a surface bloom is likely to form based on the EcoFuzz appearance value (Fig. 2.10). EcoFuzz rates the chance of surface bloom development on a scale of 1 (no scum) to 100 (very high chance of bloom). To ensure that the chance of surface bloom formation calculated by EcoFuzz is only translated to bloom formation in Delwaq under certain conditions, a scum appearance threshold value (Thres_App) can be specified as a Delwaq process parameter. Only if both the cyanobacteria biomass and appearance thresholds are exceeded will the buoyancy process then be activated in the model.

Surface scum formation

Vertical migration of cyanobacterial species to the surface waters under bloom forming conditions are simulated using a buoyancy routine within the Delwaq process library (Fig. 2.11). In order to differentiate between phytoplankton cells fully mixed in the water column and buoyant cells either in the process of forming a surface bloom or already present in the surface layers, two algal types are specified for each potential scum forming species in the model, a mixed type and a scum type. In the current study three dominant scum forming cyanobacteria species are simulated (*Microcystis* sp, *Aphanizomenon* sp. and *Planktothrix* sp.,) and in the new formulation each species can exist in either its scum or mixed type.

The scum potential value generated by EcoFuzz is used to directly regulate the proportion of cells converted from their normal type to their scum forming type. For example, if the

FIGURE 2.10 SCHEMATISATION OF ECOFUZZ AND DELWAQ INTEGRATION AND PROCESSES, INCLUDING (A) SCUM APPEARANCE AND DISAPPEARANCE POTENTIAL, (B) SCUM FORMATION AND (C) SCUM TRANSPORT. EACH PROCESS IS DESCRIBED IN MORE DETAIL IN THE FOLLOWING SECTIONS BELOW. IN BRIEF, (1) A SCUM APPEAR AND SCUM DISAPPEAR VALUE ARE CALCULATED BY ECOFUZZ WITHIN DELWAQ. (2) IF CYANOBACTERIA BIOMASS EXCEEDS THE CYANOBACTERIA THRESHOLD, AND ECOFUZZ APPEARANCE VALUE EXCEEDS THE APPEARANCE THRESHOLD, THEN BLOOM-FORMING CYANOBACTERIAL CELLS ARE CONVERTED FROM THEIR NORMAL TYPE TO SURFACE BLOOM FORMING TYPE. (4) CYANOBACTERIAL SCUM FORMERS THEN RISE TO THE SURFACE TO FORM A SURFACE SCUM, BASED ON A NEGATIVE SEDIMENTATION VELOCITY. (5) THE SURFACE SCUM IS SUBJECT TO WIND TRANSPORTATION, DETERMINED BY THE CELL SPECIFIC WIND SCALING COEFFICIENT, WIND DRAG COEFFICIENT AND DELFT3D-FLOW OUTPUT. FOR SCUM DISAPPEARANCE, (I) THE ECOFUZZ DISAPPEARANCE VALUE IS COMPARED TO A SCUM DISAPPEARANCE THRESHOLD. (II) IF THE THRESHOLD IS EXCEEDED, THE SCUM DISAPPEARANCE ROUTINE IS ACTIVATED IF A SCUM EXISTS, AND ALL SCUM FORMING TYPES ARE REVERTED BACK TO THE NORMAL NON-SCUM FORM, MIXED THROUGHOUT THE WATER MIXED LAYER. (III) IF UNDER THE THRESHOLD, THE DISAPPEARANCE ROUTINE IS NOT ACTIVATED IN THE MODEL



EcoFuzz scum appearance output is 42 for a particular time step, than 42% of the total biomass represented by a potential scum forming algal type is converted to its scum type and will form a surface scum. The same approach in reverse is implemented for scum disappearance. The proportion of cells entering the buoyancy routine in each model time step are then transported to the surface layers of the vertical grid using an algal type-specific negative sedimentation (buoyancy) rate, specified as a Delwaq process parameter.

Following activation of the buoyancy process all scum forming types will eventually accumulate in the upper most layer of the model where they will remain until the scum disappearance process is activated by the model. Growth and mortality rates for each cyanobacterial scum forming type are identical to the rates already defined for the non-scum type of the same species if the model simulates phytoplankton biomass. If biomass is not simulated by the model, there will be no change in the total biomass, although concentrations will differ between grid cells due to transport. In the current application phytoplankton biomass is not simulated by the model, but rather reset weekly based on field measurements.

Scum horizontal transport
The transportation of substances due to advection and dispersion within Delwaq is based on calculations of water velocity simulated in Delft3D-FLOW. In the water quality model, additional horizontal transport routines are applied to better simulate the spatial distribution of cyanobacterial scums following the accumulation of buoyant cells in the surface waters.

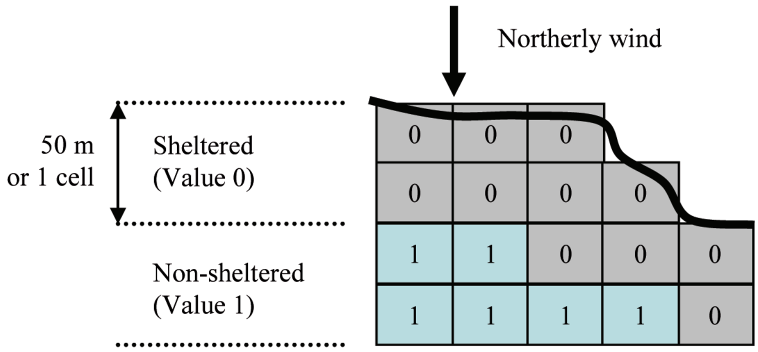
The horizontal transport of cyanobacterial scums to the lake shoreline is simulated in the model based on water velocities calculated in Delft3D-FLOW, and coupled to Delft3D-ECO. A wind drag process implemented in the Delwaq process library is used to simulate additional wind drag ($V_{WindDrag}$) on cyanobacterial cells in the surface waters following surface scum formation. Wind drag is calculated based on a wind drag coefficient ($F_{WindDrag}$, dimensionless), hourly wind speed (V_{Wind}) and direction relative to the grid orientation, using the following equation:

$$V_{WindDrag} = V_{Wind} \text{ x } F_{WindDrag} \text{ x cosine (grid angle)} \qquad \text{Equation 2.1}$$

Wind scaling
To simulate the persistence of cyanobacterial surface scums in grid cells along the sheltered shorelines of the lake, which is dependent on wind direction, or within small harbours and embayments of the lake due to less wind exposure, the wind speed used for the wind drag calculation is scaled based on a grid cell-specific multiplication factor. This value is varied depending on the dominant wind direction, with eight wind directions specified in the model (NNE, ENE, ESE, SSE, SSW, WSW, WNW and NNW).

For each lake and wind direction, the grid cells directly adjacent to the leeward shoreline or all the cells in a small embayment or harbour are assumed to be sheltered from the wind and given a multiplication factor (and therefore wind speed) of 0 (See Fig. 2.11). The remaining grid cells are then considered to be fully exposed to the wind, and given a multiplication factor of 1. In this application, the width of sheltered regions is assumed to be a distance of 50 m from the lake shoreline, or a minimum of 1 cell wide. In complete wind sheltered regions such as harbours and small embayments, all cells are considered to be wind-sheltered if the model grid was sufficiently fine enough to do so. The values for the wind multiplication factor can be altered by the user at any time should more detailed information on the localised effects of wind become available. The multiplication factor was used in calculation of the wind drag. This method was used as an approximation only for the potential effects of differences in wind fetch within the lake on horizontal surface scum transport.

FIGURE 2.11 **INCORPORATION OF GRID AND WIND DIRECTION SPECIFIC WIND SCALING**



2.4.4 SCUM DISAPPEARANCE

As for scum appearance, the scum disappearance routine is based on output from the model EcoFuzz, which is determined hourly by the model. If the scum disappearance value exceeds a given disappearance threshold value specified as a process parameter in Delwaq, then for each cyanobacterial species, biomass associated with the scum type of that species will revert back to its normal type at the rate specified according to the scum disappearance value from EcoFuzz (Fig. 2.10) The phytoplankton cells are then distributed back evenly throughout the water column based on mixing processes as simulated by Delwaq.

If the scum disappearance threshold is not exceeded, then all cyanobacterial species remain as their scum type, and all phytoplankton cells remain concentrated in the upper most layer of the water column. If there is no scum already present in the system, than scum disappearance will have no effect on the cyanobacteria distribution in the water column. The scum disappearance threshold is intended as an extra calibration point in the model, used for additional fine-tuning of the model if required.

2.4.5 MODEL TIME STEPS AND SIMULATION PERIODS

All Delwaq simulations were conducted using a computational and output time step of 1 hour, to ensure that simulations times would remain sufficiently short for use in an operational early warning system. The BLOOM and EcoFuzz models, run simultaneously within Delwaq, were also run on the same time step.

3

OPERATIONAL TESTING OF COMPLETE MODEL INSTRUMENTATION AS AN EARLY WARNING SYSTEM

3.1 INTRODUCTION

In this Chapter the operational feasibility of the cyanobacterial early warning model instrumentation, as described in Chapter 2, is examined through weekly model simulations conducted over a three-month period using a combination of forecasted and measured model input data. In the previous study conducted in 2007 (see Deltares, 2008), model simulations were always carried out as hind casts due to the time delays between data collection and delivery, as well as data processing requirements before input to the model.

The main objectives of this part of the study were to:

- Finalise the operational implementation of the model;
- Define a protocol for field data collection and delivery times to ensure that model input data based on field measurements was made available as quickly as possible for the model forecast simulations;
- Simplify and standardise the processing of model input data to allow rapid input to the model;
- Run weekly model forecast simulations using the complete model instrumentation to make daily predictions of cyanobacterial scum presence and absence for up to seven days in advance for the four test locations;
- Summarise and distribute the weekly forecasted simulation results through bulletins delivered to the local lake mangers to provide a clear and rapid overview of potential forecasted scum events and their location.

3.2 OPERATIONAL SETUP OF MODEL

The following 3 steps are required to run the complete model instrument in an operational setting for each system, based on the model setup and implementation outlined in Chapter 2:

1. Setup and run hydrodynamic model:
   a. Import latest KNMI forecasted meteorological data;
   b. Reformat meteorological data and import to flow model;
   c. Run model for hydrodynamic simulations;
2. Setup and run Water Quality model:
   a. Reformat meteorological data and import to model;
   b. Collate and reformat water quality data and import to model;
   c. Run coupling program to obtain hydrodynamic simulation results in a format able to be imported into the water quality model;
   d. Run model for hydrodynamic simulations;
3. Model output and bulletin preparation:
   a. Examine model results and create graphics;
   b. Prepare results into a bulletin and send bulletin by required time deadline.

The main input data required to run the complete model instrumentation consisted mainly of forecasted meteorological data, provided by the KNMI through Rijnland Water board, as well as water quality data in the form of phytoplankton bio volume and Chlorophyll-a concentration for the water quality model.

3.2.1 FORECASTED METEOROLOGICAL DATA

Meteorological data used as hourly input to both the hydrodynamic model (air temperature, wind speed, wind direction, cloud cover, solar radiation and relative humidity) and water quality and scum appearance model (wind speed, wind direction and solar radiation), are described in more detail in Chapter 2.

Forecasted meteorological data was delivered twice a week by Rijnland Waterboard for the geographical area Zuid Holland North West in the following format:

- Hourly forecasts for the coming 24 hours for air temperature (ºC), relative humidity (%), cloud cover (8 point), wind direction (direction), wind speed (Bft) and solar radiation (J cm^2 hr^{-1}) (File Zuid-Holland Noordwest_1uur);
- Three-hourly forecasts for the coming five days in the same form as the hourly forecast (File Zuid-Holland Noordwest_3uur);
- Daily forecasts for the coming seven days for mean and maximum daily air temperature (ºC), mean daily relative humidity (%), cloud cover (8 point), wind direction (direction) and wind speed (Bft), and daily total solar radiation (J cm^2 day^{-1}) (File Zuid-Holland Noordwest_24uur);
- Hourly forecasts for the coming 24 hours with wind speed expressed as m sec^{-1} (File VerwachtingenKort bosbo).

For the last three weeks of September, forecasted meteorological data for Rotterdam Airport was purchased directly from Meteo Consult, and consisted of forecasts for the coming seven days as hourly values with wind speed expressed as m sec^{-1} rather than Bft scale.

3.2.2 OBSERVED METEOROLOGICAL DATA

Actual measured meteorological data, although not used as part of the forecasted model runs, were downloaded directly from the KNMI FTP site twice a week. This data required little processing, as it was already in the form required for input to the model, for example wind speed expressed as m sec^{-1} rather than Bft scale. The data were available for both the Schiphol Airport and Rotterdam Airport climate stations.

3.2.3 PROCESSING OF METEOROLOGICAL DATA

Before the data could be applied in the model instrumentation, they were formatted and processed as follows to obtain hourly input for the coming 7 days:

1. The hourly, three-hourly and daily forecasted data were amalgamated;
2. Wind speed was converted from Bft scale to m sec^{-1} for all forecasts after the first 24 hours;
3. Wind direction was converted from text format to degrees;
4. Hourly values were obtained from the three-hourly data using linear interpolation;
5. Hourly values for the daily forecasted data were obtained from the previous day for which three hourly measurements were available for the parameters relative humidity and wind direction, and based on the daily available value and a mean of the previous 24 hours for temperature, cloud cover, solar radiation and wind speed.

Although the data transformation process was automated as much as possible using the raw delivered excel files, this was made difficult by changes in the data sequence, missing data noted as blanks or otherwise (e.g. -999), variations in decimal point (. or ,) and the inclusion of spaces within the data delivered as text, for example wind direction. Due to these many forms of potential errors, the final data were always checked manually after processing to ensure there were no missing values or outliers. The data were read into the model as text files, imported through the model user interface.

3.2.4 WATER QUALITY FIELD DATA

In the current study, field measurements used as input to the complete model instrumentation were largely confined to water column temperature (Flow model initial conditions) and phytoplankton data (water quality model initial phytoplankton biomass), as in the revised modelling approach changes in phytoplankton biomass due to growth and mortality were not simulated and therefore water column nutrient concentrations as well as light profiles were not required as input to the model.

It was intended that all measurements and sample collections and analysis were completed by the relevant water board or its designated commercial laboratory within five days of sample collection, so that the data could still be relevant as input to the model instrument. For the phytoplankton measurements, cell counts were simplified to cyanobacterial counts only for most lakes to ensure that a rapid turnaround time between sample collection and data delivery could be achieved. To maintain consistency in phytoplankton data counts, two commercial laboratories were used; Koeman en Bijkerk BV (Delftse Hout and Westeinderplassen) and Grontmij AquaSense (Gooimeer-Eemmeer and Sloterplas).

The type and form of data delivered for each study site varied greatly dependent on the type of field equipment available and the overall size of the lake.

Delftse Hout

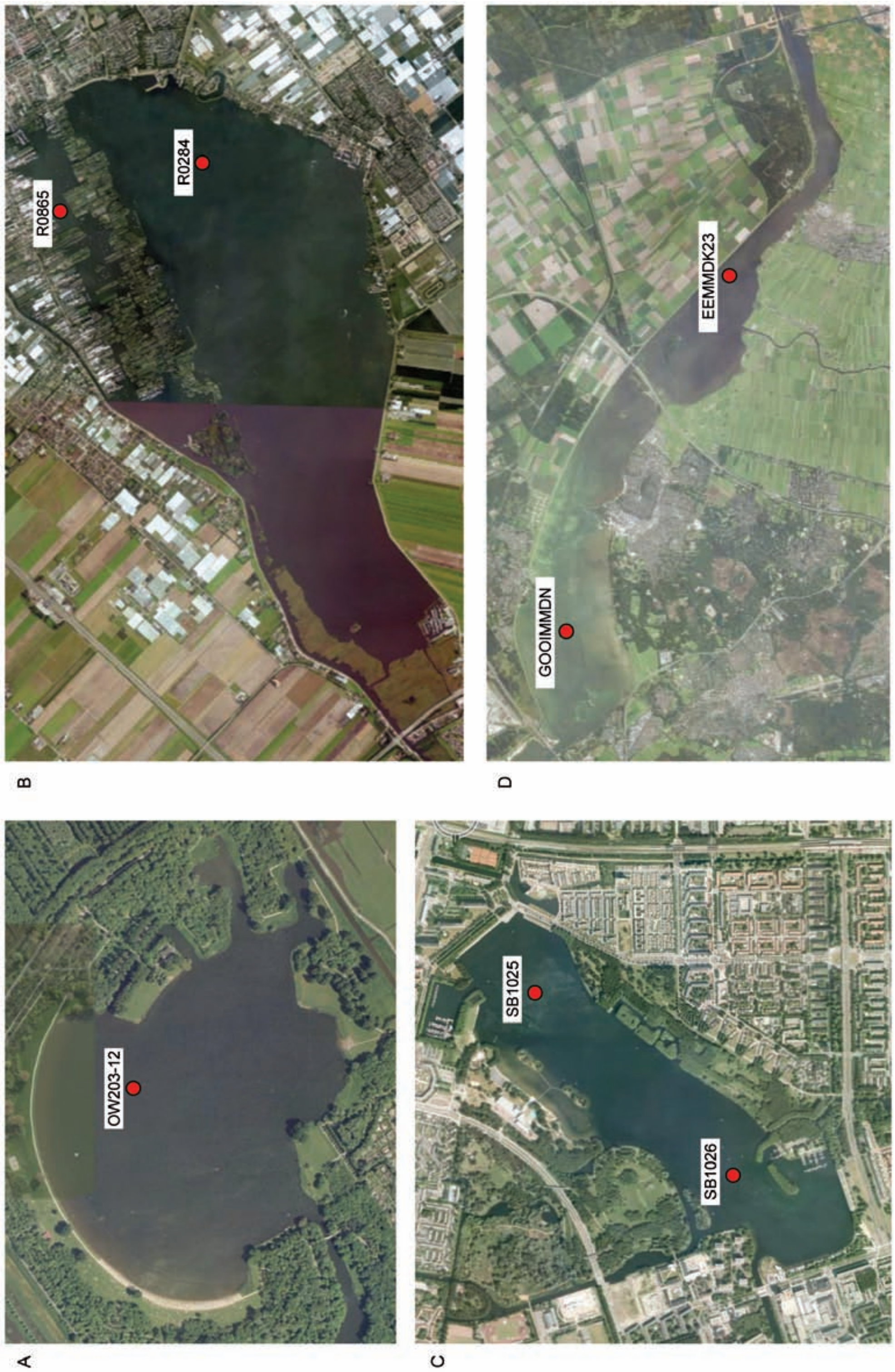
Water quality sampling was carried out at the Delftse Hout approximately every Monday morning between 2 July and 29 September 2008, with the results delivered every Thursday the same week. Depth integrated (0-2 m) water column samples were collected from five sites (OW203-111, OW203-112, OW203-113, OW203-114, OW203-116) for chlorophyll-a analysis in the laboratory, and in addition temperature profiles were collected at the same sites at 0.5 m depth intervals using a hydro lab water quality probe. Although the Hydro lab probe also had the capability to estimate cyanobacteria biomass, the results were not calibrated and could therefore not be applied in the current study. Instead water samples were collected weekly from one site (OW203-114, Fig. 3.1) for cyanobacteria cell counts and biovolume to species level.

Gooimeer and Eemmeer

For Lakes Gooimeer and Eemmeer, water samples were collected from the surface mixed layer (depth integrated 0-2 m) at one site in each lake (EEMMDK23 and GOOIMMDN, Fig. 3.1) approximately weekly on Tuesday between 1 July and 29 September 2008 for determination of phytoplankton cell counts and biovolume to species level, as well as total chl-a concentration. Water column temperature was derived from the in-situ water probes located at a site near Almere Harbour in Lake Gooimeer. The temperature data were not available for every week of the study.

The results of each weekly analysis were made available typically every Monday.

FIGURE 3.1 PHYTOPLANKTON SAMPLE SITES FOR (A) DELFTSE HOUT, (B) WESTEINDERPLASSEN, (C) SLOTERPLAS AND (D) GOOIMEER – EEMMEER. FOR SLOTERPLAS SITE SB1025 REPRESENTS SLOTERPLAS NOORD AND SB1026 SLOTERPLAS ZUID



Sloterplas

Total chlorophyll-a concentration as well as estimates of cyanobacteria, chlorophyte, diatom and cryptophyte biomass (μg L^{-1}) were measured weekly at eight locations (Sites SB1025, SB1026, 1, 4, 9, 11, 14, 17) in Sloterplas between 1 July and 6 October 2008. Phytoplankton cell counts and biovolume were measured weekly at 2 sites (Sloterplas Noord and Sloterplas Zuid, Fig. 3.1) from tube integrated water samples (depth 0-8 m).

Westeinderplassen

Water quality sampling was carried out weekly at 12 locations in the Westeinderplassen between 8 July and 23 September 2008 for estimates of cyanobacterial, chlorophyte and diatom biomass (μg L^{-1}) as well as total chlorophyll-a concentration using a portable fluoroprobe (Sites R0278, R0279, R0284, R0323, R0326, R0865, R0866, R0867, R0868, R0869 & R0870). Cyanobacterial cell counts and biovolume were determined weekly from water samples collected at 2 locations (RO284, RO865, Fig. 3.1) using a depth integrated tube sampler (0-2 m).

For input to the hydrodynamic model, initial water column temperatures were derived from the mean of all field measurements collected each week. For the water quality model, input of cyanobacteria biomass in the form of carbon biomass was based on a Chl-a:cell ratio..

3.2.5 PROCESSING OF WATER QUALITY FIELD DATA

Algal concentrations used to prescribe the initial starting conditions for each species or taxonomic group in the model resets were based on the field measurements of chlorophyll-a concentration and estimates of species biovolume derived from weekly cell counts. The phytoplankton biovolume measured weekly in each lake is shown in Figure 3.2 (Westeinderplassen) and Figure 3.3 (Delftse Hout, Gooimeer, Eemmeer, Sloterplas). For each lake and restart date, the mean total chlorophyll-a concentration was proportioned into each model taxonomic group (chlorophytes and diatoms) or species (*Microcystis* sp, *Aphanizomenon* sp., *Planktothrix* sp.) based on the total measured biovolume for each group or species.

For the cyanobacteria, additional minor species not directly represented in the model were assigned to one of the three modelled species based on their morphology. For example, counts of *Anabaena* sp., a filamentous species, were included as *Aphanizomenon* sp. The biovolume of all species not in the cyanobacteria, chlorophytes or diatom taxonomic groups were divided equally between chlorophytes and diatoms.

The resulting chlorophyll-a concentration for each input group was then divided by the Carbon:chlorophyll-a ratio to obtain an estimate of carbon biomass for direct input to the model. Although it is well known that C-chlorophyll-a ratios vary between taxonomic groups and individual species, values documented in the literature also suggest a high degree of variability within a species due to changing nutrient limitation states and light availability. An average Carbon:chlorophyll-a ratio of 40 was therefore assigned for all phytoplankton species and groups in this study.

FIGURE 3.2 MEAN MEASURED WEEKLY PHYTOPLANKTON BIOVOLUME FOR WESTEINDERPLASSEN, 7 JULY (WEEK 1) TO 29 JULY (WEEK 15). BIOVOLUME UNITS ARE MM³ L⁻¹

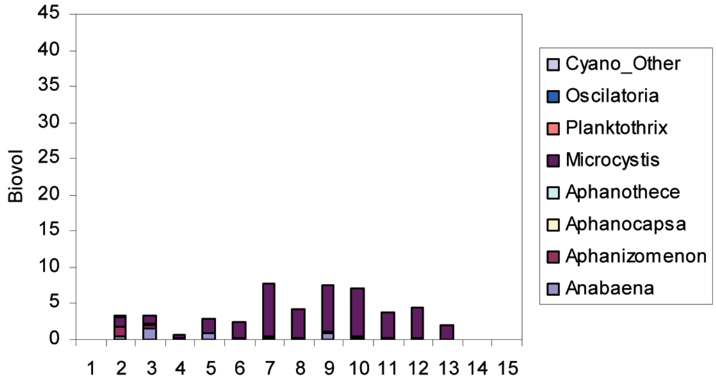
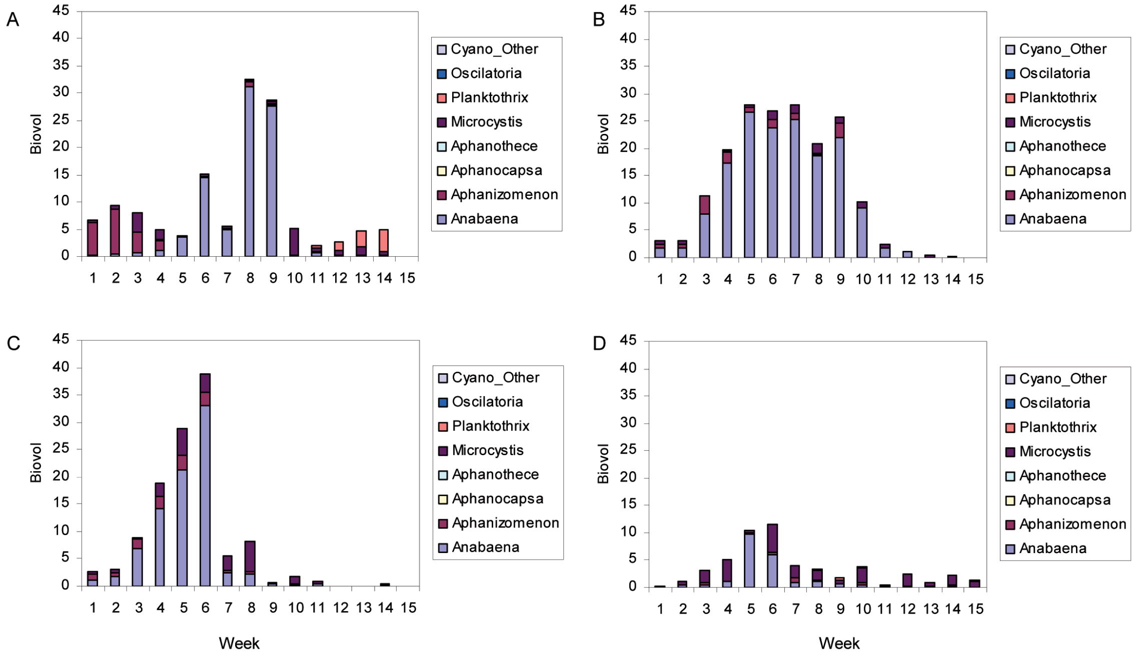


FIGURE 3.3 MEAN MEASURED WEEKLY PHYTOPLANKTON BIOVOLUME FOR (A) DELFTSE HOUT, (B) GOOIMEER, (C) EEMMEER AND (D) SLOTERPLAS, 7 JULY (WEEK 1) TO 29 JULY (WEEK 15). BIOVOLUME UNITS ARE MM³ L⁻¹



3.3 MODEL OPERATION AND PROTOCOLS

At the start of this study, the following concerns were identified with the operation of the complete model in forecasting mode:

- The model remains complex as the complete instrument consists of a hydrodynamic flow model and coupled water quality-fuzzy logic model which require input data especially if the model is to be reset weekly due to the exclusion of processes simulating changes in phytoplankton biomass.
- Phytoplankton biomass is not modelled in the current approach, but rather reset weekly. Phytoplankton biomass and the appearance and disappearance of surface scums is highly variable in both space and time, and therefore field sampling should be carried out at several locations across the lake if this variability is to be included in the model resets

- Time delays exist between sample collection and analysis, particularly for estimates of phytoplankton biomass and species composition which is most accurate when quantified using microscopy enumeration techniques, although the use of a fluoroprobe may be used to approximate biomass if calibrated accurately against actual measurements.
- The type and form of data used to reset the model for individual lakes is likely to vary greatly due to differences in sampling equipment and existing sampling programs between the water boards, as well the differences in lake size, and therefore sampling intensity required to best monitor the system.
- Due to the nature of field work, data collection is very susceptible to the weather conditions, and data collection and supply can therefore not be guaranteed and an alternative data source should be considered when this occurs.
- Model simulations can be time intensive, although simulation times can be reduced through lower simulation time frames and higher time steps.
- Model output of cyanobacterial scums may be difficult to interpret, as the model computes scum concentrations for every cell in the model grid and for each time step, while field sampling is often limited in space and time;
- The model results must be presented in a form easily able to be used by water managers, whose main interest in the results is scum presence and absence, as well as location for example along a specific shoreline.
- Despite the many possibilities for potential delays in model simulations, the model forecasted results must be communicated before scum events occur in order for the system to truly operate in an early warning context.

Based on these points a number of tasks were implemented to simplify the model setup and reduce the pressure on data requirements and delivery, and protocols were established to streamline data sources and delivery times, and collectively improve overall model reliability (sections 3.3.1 - 3.3.3).

3.3.1 MODEL INPUT SIMPLIFICATION

Reduction of model input requirements

In the current modelling approach phytoplankton biomass is not simulated by the model, and it was therefore decided to reset the model weekly with phytoplankton biomass based on field measurements. To reduce delays associated with the detailed analysis of phytoplankton samples collected from the field, it was decided that for most study lakes only cyanobacteria species would be enumerated. This has no effect on model predictions as the biomass of other taxonomic groups are not relevant for the forecasting of cyanobacterial scums in the current model approach.

Spatial variability of phytoplankton

To ensure that the spatial variability in cyanobacterial scums was incorporated in the weekly model resets, a combination of cyanobacterial cell counts and chlorophyll-a fluorescence and cyanobacterial probe, measurements were used to restart the model weekly. As phytoplankton biovolume and chlorophyll-a concentrations were available for multiple sites for each lake, the phytoplankton input to the model was varied spatially as follows:

Delftse Hout	5 zones
Gooimeer-Eemmeer	16 zones
Sloterplas	8 zones
Westeinderplassen	12 zones

3.3.2 DATA DELIVERY PROTOCOLS AND MODEL RUN TIMES

For the Delftse Hout, the model was run each Friday and for the remaining three lakes, each Monday. To ensure that the forecast bulletins could be delivered on time, the following data protocols were introduced (see also Table 3.1):

1. KNMI forecasted meteorological data were to be delivered by email before 9:00 each model day;
2. Water quality data (phytoplankton biovolume and chlorophyll-a concentration) were to be delivered by email before 17:00 the day before each model simulation day;
3. Should the chlorophyll-a data not be available the data from the previous week would be used instead;
4. Should the biovolume or meteorological data not be available the model would not be run that week;
5. Forecast bulletins would be delivered by email before 17:00 each model day.

The water quality data used as input to the model were derived from field sampling carried out several days before, dependent on the amount of processing time required to analyse the samples. For example, for the Delftse Hout, where the model was run on every Friday, the water quality data were collected 2 days before the forecast model runs while for the remaining lakes which were simulated every Monday, the samples used were collected up to six days before.

TABLE 3.1 SUMMARY OF DATA STREAMS FOR THE TEST PHASE OF EWACS MODEL INSTRUMENT 2008

Data		DH	GE	SP	WP
Biovolume	*Source*	K&B	Aqualab	Aqualab	K&B
	Delivery	Thursday 17:00	Friday 17:00	Friday 17:00	Friday 17:00
Total Chlorophyll-a	*Source*	Delfland	IJG	Waternet	Rijnland
(filtered, ug/l)	*Delivery*	Thursday 17:00	Friday 17:00	Friday 17:00	Friday 17:00
Fluoro probe	*Source*	Delfland	IJG	Waternet	Rijnland
(Chl-a & cyano, ug/l)	*Delivery*	Thursday 17:00	*Friday 17:00	Friday 17:00	Friday 17:00
Validation data	*Source*	Delfland	IJG	Waternet	Various
(presence/absence & categories	*Delivery*	Thursday 17:00	**Friday 17:00	Friday 17:00	***Wednesday 17:00
Temperature	*Source*	Delfland	IJG	Waternet	Rijnland
(degC)	*Delivery*	Thursday 17:00	Friday 17:00	Friday 17:00	Friday 17:00
Climate forecast delivery (Rijnland)		Friday 9:00	Monday 9:00	Monday 9:00	Monday 9:00
Model forecast delivery (Deltares)		**Friday 17:00**	**Monday 17:00**	**Monday 17:00**	**Monday 17:00**

3.3.3 MODEL OUTPUT AND BULLETIN GENERATION

An important component of the forecasted cyanobacterial model runs was the communication of the model results to the water boards in time to be beneficial for use as an early warning system. As the model produces results for every time step (hourly) and every cell in the model grid, it was important that the results were presented as a general overview of the system. For this reason it was decided to present the results as bulletins comprised of the following information:

1. Summary of data delivery times, including:
   - date and time meteorological and water quality data delivered;
   - forecast simulation period
2. Summary of model results for the coming seven days at 13:00 each day:
   - scums presence or absence and location;
3. Summary of daily forecasted meteorological conditions;
4. Plots of the model results for the coming seven days at 13:00 each day.

Scum presence or absence was based on model output for cyanobacterial biomass in the surface layer of the lake, expressed as units of carbon per square meter (g cyano C m^{-2}), which represents the final end product of both surface bloom appearance and disappearance routines simulated by the model. Spatial aggregation was used to average the model results over various pre-defined zones within the model grid, similar to the zones already used for the field validation sampling. The total number of spatial zones applied to each lake was:

Delftse Hout	5 zones
Gooimeer-Eemmeer	16 zones
Sloterplas	8 zones
Westeinderplassen	12 zones

3.4 RESULTS OF TRIAL

3.4.1 FORECAST BULLETIN DELIVERY

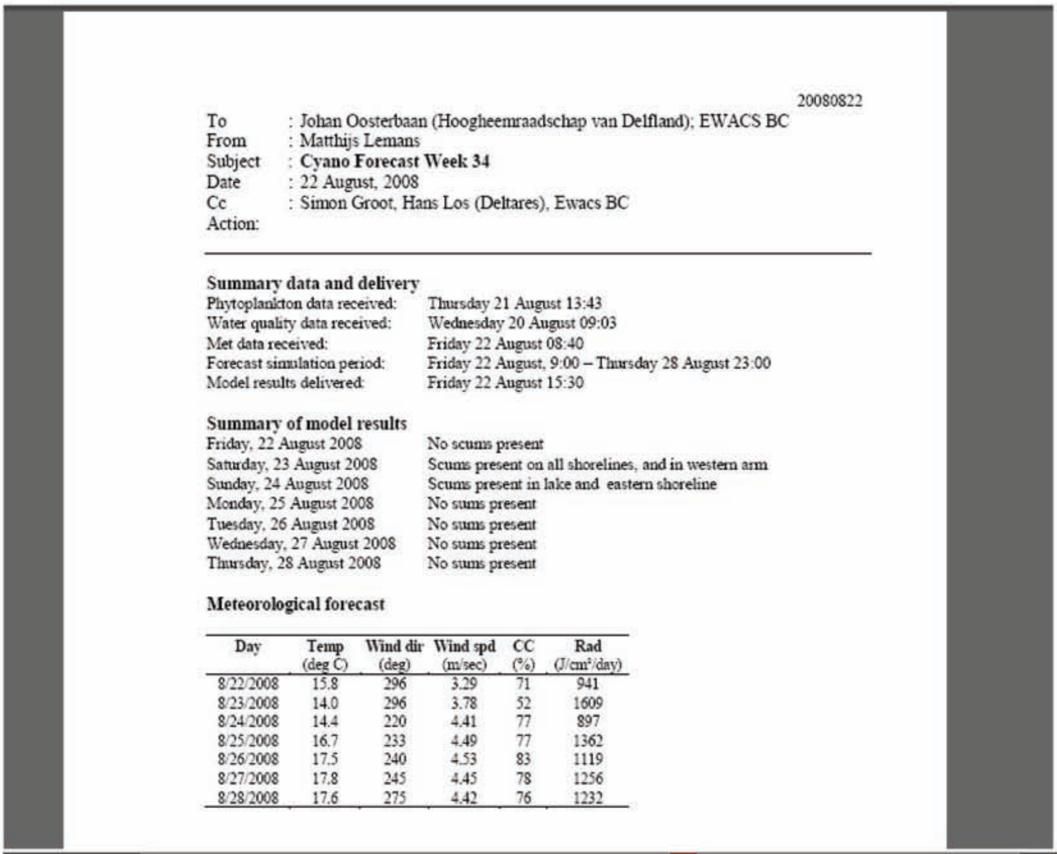
Forecasted meteorological data were available between 11 July and 14 October 2008, while water quality data were available between 7 July and 23 September (Westeinderplassen) or 30 September 2008 (remaining lakes). The complete model forecast system was run weekly between 7 July and 30 September for all lakes for which there was data available on time each week (Table 3.2). An example of the final bulletins produced weekly for each lake is shown in Figure 3.4.

For the Delftse Hout and Gooimeer-Eemmeer, 10 and 9 bulletins were produced, respectively, over the 13 week study period. In both systems, 1 bulletin was not produced due to a lack of manpower to run the models, while two bulletins were not produced due to problems with the timely delivery of Chlorophyll-a concentration. For the Sloterplas, seven bulletins were produced, with six weeks not delivered due to delays in the delivery of phytoplankton biovolume. In the Westeinderplassen, only one bulletin was produced as a forecast, due to problems with the delivery of biovolume and/or Chlorophyll-a.

TABLE 3.2 SUMMARY OF FORECAST BULLETINS PRODUCED USING THE COMPLETE EARLY WARNING SYSTEM FOR DELFTSE HOUT (DH), GOOIMEER-EEMMEER (GE), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP). SAMPLE DATE REPRESENTS THE DATE OF WATER QUALITY SAMPLE COLLECTION

	DH			GE			SP			WP		
Week	Sample date	Forecast start	Forecast end	Sample date	Forecast start	Forecast end	Sample date	Forecast start	Forecast end	Sample date	Forecast start	Forecast end
28	7 Jul	11 Jul	17 Jul	9 Jul	14 Jul	20 Jul	7 Jul	x	x	9 Jul	x	x
29	14 Jul	21 Jul	27 Jul	15 Jul	21 Jul	27 Jul	14 Jul	x	x	15 Jul	x	x
30	21 Jul	25 Jul	31 Jul	22 Jul	x	x	21 Jul	x	x	22 Jul	x	x
31	28 Jul	x	x	29 Jul	4 Aug	9 Aug	28 Jul	x	x	29 Jul	x	x
32	4 Aug	8 Aug	14 Aug	5 Aug	11 Aug	17 Aug	4 Aug	11 Aug	17 Aug	5 Aug	x	x
33	11 Aug	15 Aug	21 Aug	12 Aug	18 Aug	24 Aug	11 Aug	18 Aug	24 Aug	12 Aug	x	x
34	18 Aug	22 Aug	28 Aug	19 Aug	25 Aug	31 Aug	18 Aug	25 Aug	31 Aug	21 Aug	x	x
35	25 Aug	x	x	26 Aug	x	x	26 Aug	1 Sep	7 Sep	26 Aug	x	x
36	2 Sep	5 Sep	11 Sep	2 Sep	x	x	1 Sep	8 Sep	14 Sep	2 Sep	x	x
37	8 Sep	12 Sep	18 Sep	9 Sep	15 Sep	21 Sep	8 Sep	x	x	9 Sep	15 Sep	21 Sep
38	15 Sep	19 Sep	25 Sep	16 Sep	22 Sep	28 Sep	15 Sep	22 Sep	28 Sep	16 Sep	x	x
39	22 Sep	26 Sep	2 Oct	23 Sep	29 Sep	5 Oct	22 Sep	29 Sep	5 Oct	23 Sep	x	x
Total bulletins		10			9			7			1	

FIGURE 3.4 EXAMPLE OF WEEKLY CYANOBACTERIAL FORECAST BULLETIN PRODUCED FOR EACH LAKE DURING THE COURSE OF THE STUDY



20080822

To : Johan Oosterbaan (Hoogheemraadschap van Delfland); EWACS BC
From : Matthijs Lemans
Subject : **Cyano Forecast Week 34**
Date : 22 August, 2008
Cc : Simon Groot, Hans Los (Deltares), Ewacs BC
Action:

Summary data and delivery

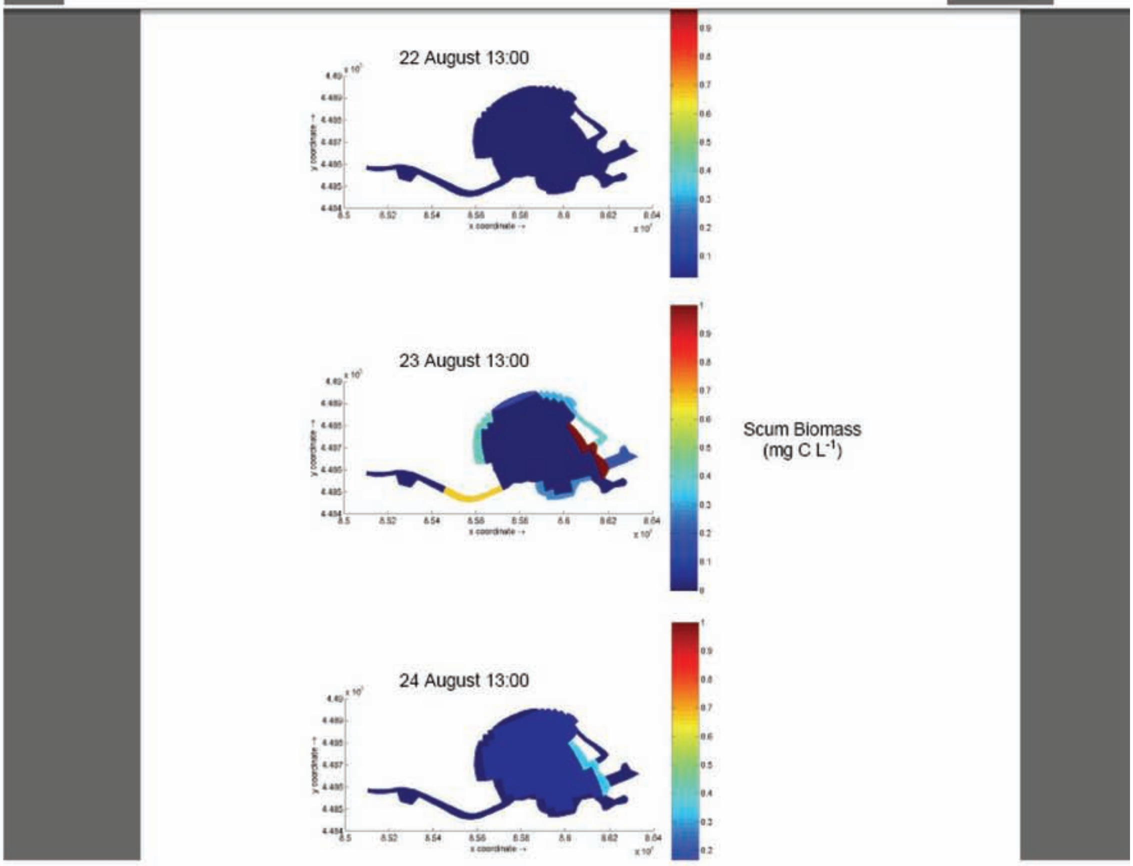
Phytoplankton data received:	Thursday 21 August 13:43
Water quality data received:	Wednesday 20 August 09:03
Met data received:	Friday 22 August 08:40
Forecast simulation period:	Friday 22 August, 9:00 – Thursday 28 August 23:00
Model results delivered:	Friday 22 August 15:30

Summary of model results

Friday, 22 August 2008	No scums present
Saturday, 23 August 2008	Scums present on all shorelines, and in western arm
Sunday, 24 August 2008	Scums present in lake and eastern shoreline
Monday, 25 August 2008	No sums present
Tuesday, 26 August 2008	No sums present
Wednesday, 27 August 2008	No sums present
Thursday, 28 August 2008	No sums present

Meteorological forecast

Day	Temp (deg C)	Wind dir (deg)	Wind spd (m/sec)	CC (%)	Rad (J/cm²/day)
8/22/2008	15.8	296	3.29	71	941
8/23/2008	14.0	296	3.78	52	1609
8/24/2008	14.4	220	4.41	77	897
8/25/2008	16.7	233	4.49	77	1362
8/26/2008	17.5	240	4.53	83	1119
8/27/2008	17.8	245	4.45	78	1256
8/28/2008	17.6	275	4.42	76	1232



4

VALIDATION OF CURRENT MODEL SYSTEM

4.1 INTRODUCTION

In this chapter the results of the weekly model output for cyanobacterial surface scum presence, absence and location were compared to the field validation data available to assess model performance. Model runs were conducted using both the forecasted meteorological data, as described in Chapter 3, and as hind casts using observed meteorological data.

4.2 MODEL SIMULATIONS

For all four lakes the model was run weekly between early 7 July and 30 September 2008 using forecasted meteorological data to test the operational feasibility of the complete model instrumentation as an early warning system for weeks in which there was adequate input data to run the models (see Table 3.1).

At the end of the three-month test period all model runs based on the forecasted meteorological data were updated, and then re-simulated using also observed meteorological data (Table 4.1). Revisions of the model setup and simulation runs included:

- Simulation of all forecasted runs not completed as part of the operational test due to missing input data (23 runs total for all lakes, see Table 3.1);
- Updating of missing phytoplankton biovolume and chlorophyll-a concentrations values for all runs in which mean values or values from the previous week were applied;
- Updating of all phytoplankton biovolume data for Sloterplas based on new biovolume estimates provided by the laboratory at the end of the study period;
- Import of observed meteorological data for both the hydrodynamic and water quality models and simulation of all weekly periods for all lakes using the new input data, and;
- Updating of spatial aggregation zones applied to Lake Gooimeer to better examine output of model scums along the lake shoreline.

The model setup applied in the current study was identical to that used in the 2007 study (see Deltares, 2008), as outlined in this report in Chapter 2.

4.2.1 MODEL OUTPUT

Spatial aggregation was used to obtain model output of cyanobacterial biomass in the surface layer of the lake, expressed as units of carbon per square meter (g cyano C m^{-2}), for several pre-defined zones within the model grid similar to the zones already used for the field validation sampling. The concentration of scum forming cyanobacteria represents the end product of both surface bloom appearance and disappearance routines simulated by the model. The total number of special aggregation zones varied per lake due to differences in lake surface area. The final number of aggregate zones applied per lake were as follows:

Delftse Hout	12 zones
Gooimeer-Eemmeer	60 zones
Sloterplas	19 zones
Westeinderplassen	39 zones

TABLE 4.1 SUMMARY OF FINAL FORECAST AND HIND CAST MODEL DELFTSE HOUT (DH), GOOIMEER-EEMMEER (GE), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP). SAMPLE DATE REPRESENTS THE DATE OF WATER QUALITY SAMPLE COLLECTION

	Sample date				DH		GE, SP, WP	
Week	DH	GE	SP	WP	Forecast start	Forecast end	Forecast start	Forecast end
28	7 Jul	9 Jul	7 Jul	9 Jul	11 Jul	17 Jul	14 Jul	20 Jul
29	14 Jul	15 Jul	14 Jul	15 Jul	21 Jul	27 Jul	21 Jul	27 Jul
30	21 Jul	22 Jul	21 Jul	22 Jul	25 Jul	31 Jul	28 Jul	3 Aug
31	28 Jul	29 Jul	28 Jul	29 Jul	1 Aug	7 Aug	4 Aug	9 Aug
32	4 Aug	5 Aug	4 Aug	5 Aug	8 Aug	14 Aug	11 Aug	17 Aug
33	11 Aug	12 Aug	11 Aug	12 Aug	15 Aug	21 Aug	18 Aug	24 Aug
34	18 Aug	19 Aug	18 Aug	21 Aug	22 Aug	28 Aug	25 Aug	31 Aug
35	25 Aug	26 Aug	26 Aug	26 Aug	29 Aug	4 Sep	1 Sep	7 Sep
36	2 Sep	2 Sep	1 Sep	2 Sep	5 Sep	11 Sep	8 Sep	14 Sep
37	8 Sep	9 Sep	8 Sep	9 Sep	12 Sep	18 Sep	15 Sep	21 Sep
38	15 Sep	16 Sep	15 Sep	16 Sep	19 Sep	25 Sep	22 Sep	28 Sep
39	22 Sep	23 Sep	22 Sep	23 Sep	26 Sep	2 Oct	29 Sep	5 Oct

4.3 FIELD VALIDATION DATA

Spatial validation data were collected as frequently as possible from each study site over the duration of the three-month study period. The collection of these data were largely reliant on input from dedicated members of the public either living on the lake shore or regularly using the lake for recreational or commercial activities.

To provide more information on the intensity of cyanobacterial scums when present, surface scums were scored according to various scum categories. In the 2007 study, four scum categories were defined but these were revised to three categories in the present study due to the similarities between original category 3 and 4:

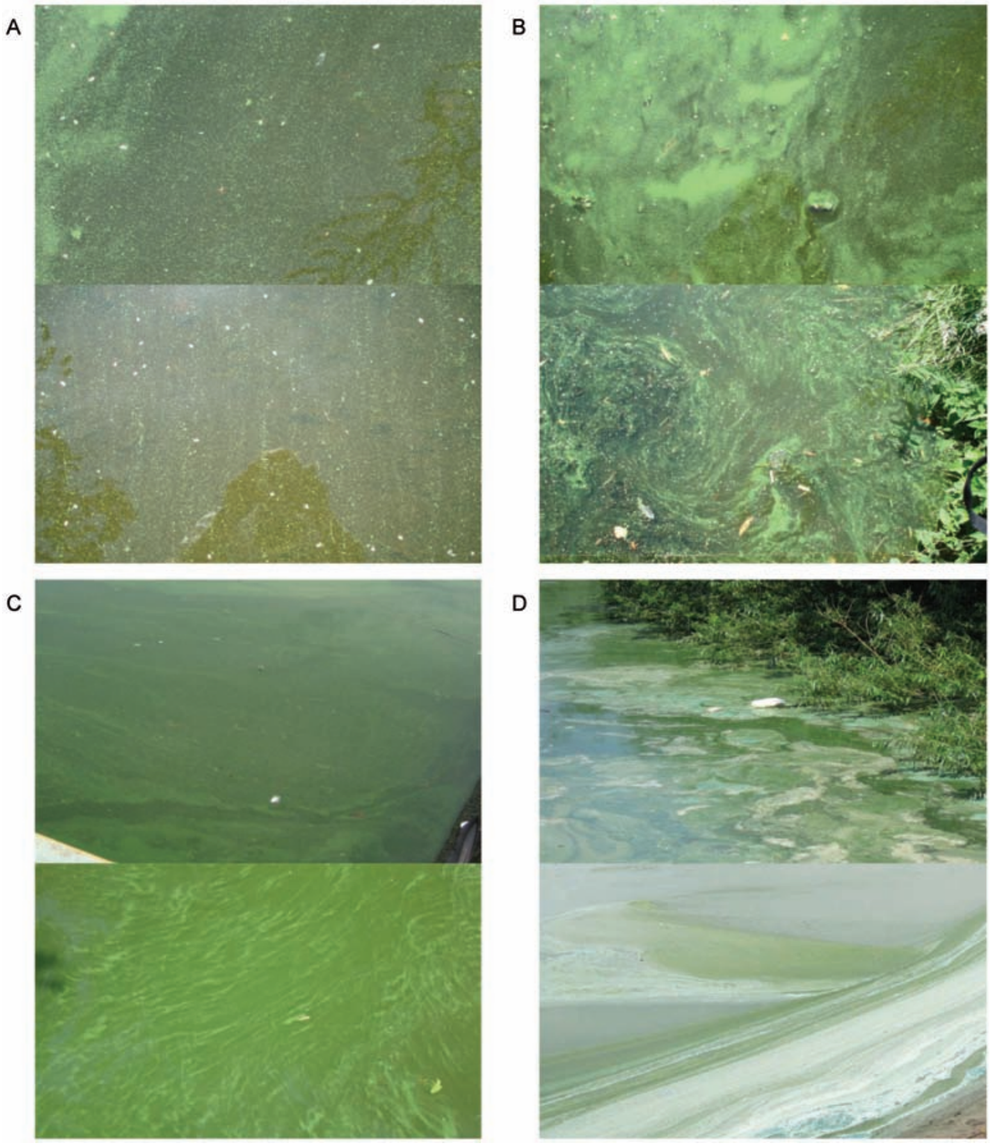
Category 1 Colonial cells or filaments present in the surface waters but visibility through the water column is generally not obscured. There are no large, inter-connected surface scums (> 10 cm^2) and there is no odour present;

Category 2 A large number of cells and filaments are present in the surface waters with water column visibility obscured in places. Inter-connected patches (> 10 cm^2) of scums exist but there is no odour present;

Category 3 Very high densities of cells and filaments present on the water surface and water column visibility is mostly or completely obscured. Coloured surface scums may be bright green or light blue, and are not easily mixed back into the water column. Foam may potentially be present as well as strong odours.

All field validation staff were provided with detailed description of the three scum categories, as well as example images for each category (Fig. 4.1). The methods applied to obtain the validation data varied between the different locations, from surveys on foot around the full shoreline of the lake (Delftse Hout) to boat surveys (Westeinderplassen) and aeroplane surveys (Gooimeer-Eemmeer). The number of predefined shorelines areas for which the field data was collected also varied between the different locations, dependent on the overall size of the lake, as discussed in the following sections.

FIGURE 4.1 CYANOBACTERIAL SCUM CATEGORIES DEFINED IN THE STUDY: (A) CATEGORY 1, (B) CATEGORY 2 AND (C) PLUS (D) CATEGORY 3



4.3.1 DELFTSE HOUT

The validation data collected was most complete for Delftse Hout, where observations were recorded for every lake shore on every week day and some weekends at around 11:00 am each day between 1 July and 30 September 2008. A total of 11 zones were used to mark the location of scums in the Delftse Hout (Fig. 4.2). During the modelling period (11 July – 2 October 2008), data were available on 55 days, with category 1 scums recorded on 55 of these days and category 2 scums on 6 days.

4.3.2 GOOIMEER - EEMMEER

Validation data were collected on a total of 15 days for Gooimeer and Eemmeer over the model simulation period (14 July to 5 October 2008) using boat surveys (10 occasions) and/ or aeroplane surveys (14 occasions) to note scum presence, absence and category at 27 locations in the lakes (Fig. 4.3 and 4.4). On eight occasions the boat surveys coincided with the aeroplane surveys, although the aeroplane surveys always recorded higher scum categories than the boat survey for the same location and approximate time on the same day. For the Gooimeer, category 1 scums were recorded on 13 days and category 2 scums on four days. For the Eemmeer, category 1 scums were recorded on 12 days while category 2 scums on only three days.

4.3.3 SLOTERPLAS

For the Sloterplas, field validation data were collected by local residents for 19 zones (Fig. 4.5) over 59 days of the model simulation period (14 July to 5 October 2008). The data were recorded on specially printed field survey books provided to each participant, with the books sent to Deltares for processing at the end of every week or fortnight.

The Sloterplas had the highest number of days on which a category 2 scum was recorded (total 38) compared to the other three study lakes. Category 1 scums were recorded on 38 of the study days. There were at times differences in the cyanobacterial scum categories recorded between small adjacent zones by different field observers, where differences were not expected.

4.3.4 WESTEINDERPLASSEN

Validation data were collected for the Westeinderplassen based on 25 boat surveys over the course of the simulation period (14 July to 5 October 2008). Each boat operator was asked to record the route followed on a provided map, and record scum presence, absence and scum category along the way. The maps were then sent to Deltares for processing, with the information provided translated to 39 zones within the lake. The path followed by the boat varied highly between different validation days, but were mostly centered on the northern reaches of the lake. Category 1 scums were recorded on 20 of the validation days while category 2 scums were recorded on 12 of the validation days.

FIGURE 4.2 SHORELINES LOCATIONS USED IN DAILY VALIDATION SURVEYS FOR DELFTSE HOUT

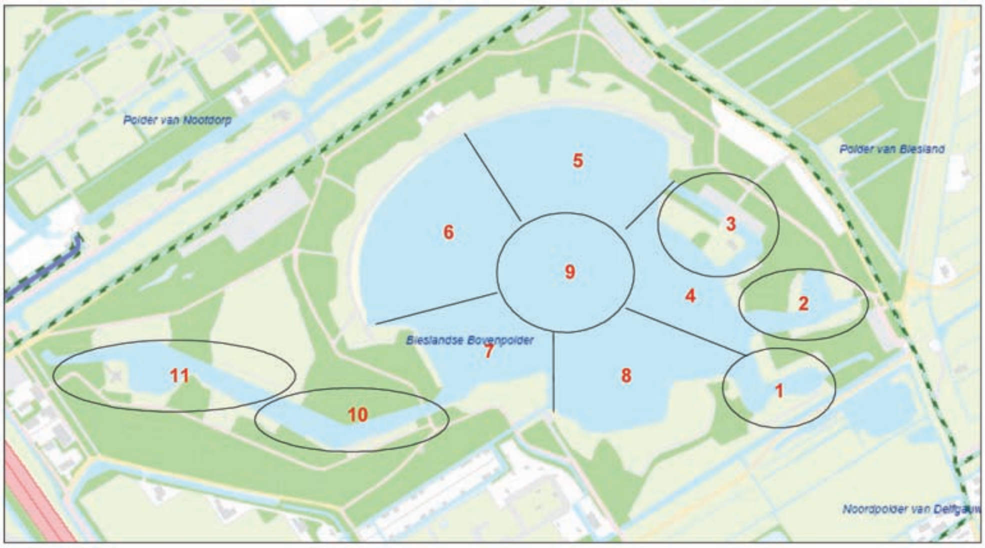


FIGURE 4.3 SHORELINES LOCATIONS USED IN DAILY VALIDATION SURVEYS FOR GOOIMEER-EEMMEER. NOTE NOT ALL LOCATIONS WERE SAMPLED EACH DAY. THE 14 POINT LOCATIONS (GREEN SQUARES) WERE SUPPLEMENTED BY ADDITIONAL ZONES ALONG EACH LAKE SHORELINE

FIGURE 4.4 EXAMPLE OF AERIAL PHOTOGRAPHS SHOWING SURFACE BLOOM PRESENCE IN THE GOOIMEER-EEMMEER

4.4 USE OF VALIDATION DATA TO ASSESS MODEL PERFORMANCE

To quantitatively assess model performance, the model results for cyanobacterial scum presence and absence were scored against the available field data for each study lake for model simulations conducted with both the forecasted and observed meteorological data. Model scum presence or absence was based on output of cyanobacterial biomass in the surface layer of the lake, expressed as units of carbon per square meter (g cyano C m^{-2}), which represents the final end product of both surface bloom appearance and disappearance routines simulated by the model. Spatial aggregation was used to average the model results over various pre-defined zones within the model grid, similar to the zones already used for the field validation sampling. Scoring of the model for each lake and on each day was based on:

FIGURE 4.5 SHORELINES LOCATIONS USED IN DAILY VALIDATION SURVEYS FOR SLOTERPLAS

1 Field scum present, model scum present;
2 Field scum present, model scum absent;
3 Field scum absent, model scum absent;
4 Field scum absent, model scum present
5 Model scum present, no field data, and;
6 Model scum absent, no field data.

The sum of score (1) and (3) represent the total number correct, and the sum of (2) and (4) the total number incorrect. The results of (5) and (6) are only reported as there is no further means to validate these scores.

In this assessment, the maximum biomasses of surface scum forming cyanobacteria of all aggregated zones across each lake were compared to the field data. As the model output represents a concentration and the field data a scum category, a number of intermediate steps were taken to translate the model output to the field data as part of the validation process. A model scum biomass threshold of 1 g C m^{-2} cyano was used in the first instance to differentiate between a true and non model scum event, and only field category 2 or greater scums were considered to be true field scum events. Therefore in validating the model, model scum presence scored correct if the model concentration was greater than 1 g C m^{-2} and the field validation category greater than or equal to 2.

The model was scored at the mean validation data collection time each day, and due to the slight differences in daily timing of the field data collection, the maximum model scum biomass over a 2 hour period immediately before and after the mean field collection time was applied to compensate for this.

The model result scores were statistically compared to the field data using the Cohen's kappa test, which is a measure of inter-rater agreement between two qualitative items.

The scores of the Cohen's kappa test can be interpreted as follows:
< 0 No agreement
0.0 — 0.20 Slight agreement
0.21 — 0.40 Fair agreement
0.41 — 0.60 Moderate agreement
0.61 — 0.80 Substantial agreement
0.81 — 1.00 Almost perfect agreement

4.5 MODEL RESULTS

The results of the model simulations conducted using both the forecasted and observed meteorological data, relative to the field validation data are shown in Figures 4.6 and 4.7, respectively. The results of the model scores, based on the methodology outlines in Section 4.4, are provided in Table 4.2 (model forecasts) and Table 4.3 (model hind casts).

Delftse Hout
Model scores for total number correct were in the order of 47% based on category 1 scums or greater for simulations conducted with the forecasted data as well as observed data. The total score for total model correct was also identical between both simulations.

When category 2 scums or greater were applied the total correct model score was 12% lower for simulations conducted using the forecasted meteorological data compared to the simulations with observed meteorological. The total number of category 2 scums predicted by the model was also lower in the forecasts (38%) compared to the hind casts (56%) (Table 4.3).

In the Delftse Hout a large number of false positive events were forecasted by the model in all simulations.

Gooimeer-Eemmeer
For the Gooimeer the total number of correct forecasts was 33% when using category 1 scums or greater, which was 7% lower than simulations made with the observed meteorological data. When category 2 scums or greater were applied the model performed much better, with scores of 80% and 73% total correct for simulations using the forecasted and observed meteorological data, respectively. Scores for total scums correct ranged from 30% for category 1 scums or greater, to 80% for category 2 scums or greater, with little (< 6%) difference between observed and forecasted input simulations.

The results for the Eemmeer were similar to that for the Gooimeer, with total model correct ranging from 33% (forecast category 1 scums or greater) to 80% (forecast data category 2 scums or greater). For both systems the data available for scoring the model was limited. A large number of scum events were simulated by the model on days for which there was no validation data available to validate the model output.

Sloterplas
In the Sloterplas model scores were better for the results of the simulations with observed meteorological data than for those with the forecasted data. The best model total correct score was 58% using category 1 scums or greater, or 54 using category 2 scums or greater. Total model correct sores were 63% for the observed data simulations, more than twice as high than simulations with the forecasted data. In the forecast data simulations a large

number of false negative (model no, field yes) events occurred while in the observed data false positive events dominated.

There were a number of periods when the model results were unrealistic, for example around 20 August 2008, due to numerical instabilities which were later found to be associated with the wind drag coefficient in the latter part of this study. These periods were removed from the scoring analysis. In the Sloterplas validation data the majority of scums observed were category 2 or greater, with the total number of these scum events being at least twice as high as that observed in all other lakes.

Westeinderplassen

In the Westeinderplassen the total number of model correct scores ranged from 28% (using category 1 scums or greater, forecast data) to 60% (category 2 scums or greater, forecast data). The total model scum corrects scores were low (10-25%), although the validation data available to score the model was very limited.

TABLE 4.2 SUMMARY OF MODEL PERFORMANCE FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR SIMULATIONS CONDUCTED USING FORECASTED METEOROLOGICAL DATA. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. CATEGORY THRES REPRESENTS FIELD CATEGORY APPLIED TO THE MODEL SCORE, BIOMASS THRES MODEL BIOMASS THRESHOLD APPLIED, AND CORRECT AND INCORRECT THE TOTAL ACCURATE AND INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA, RESPECTIVELY, AS A TOTAL OR % OF THE TOTAL

Lake	Category thres.	Biomass thres	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Total correct	Total incorrect	ND	% correct	% scums correct
DH	**1**	1	15	11	16	18	12	8	27	29	24	48%	45%
	2	1	6	20	16	10	20	8	26	30	24	46%	38%
GM	**1**	1	4	1	30	9	1	34	5	10	64	33%	31%
	2	1	3	2	30	1	9	34	12	3	64	80%	75%
EM	**1**	1	3	2	28	6	4	36	7	8	64	47%	33%
	2	1	3	2	28	0	10	36	13	2	64	87%	100%
SP	**1**	1	6	4	1	36	14	19	20	40	20	33%	14%
	2	1	5	5	1	26	24	19	29	31	20	48%	16%
WP	**1**	1	2	0	6	18	5	48	7	18	54	28%	10%
	2	1	2	0	6	10	13	48	15	10	54	60%	17%

TABLE 4.3 SUMMARY OF MODEL PERFORMANCE FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR SIMULATIONS CONDUCTED USING OBSERVED METEOROLOGICAL DATA. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. CATEGORY THRES REPRESENTS FIELD CATEGORY APPLIED TO THE MODEL SCORE, BIOMASS THRES MODEL BIOMASS THRESHOLD APPLIED, AND CORRECT AND INCORRECT THE TOTAL ACCURATE AND INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA, RESPECTIVELY, AS A TOTAL OR % OF THE TOTAL

Lake	Category thres.	Biomass thres	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Total correct	Total incorrect	ND	% correct	% scums correct
DH	**1**	1	15	10	17	18	12	8	27	28	25	49%	45%
	2	1	9	16	17	7	23	8	32	23	25	58%	56%
GM	**1**	1	5	1	37	8	1	27	6	9	64	40%	38%
	2	1	3	3	37	1	8	27	11	4	64	73%	75%
EM	**1**	1	5	2	31	7	1	33	6	9	64	40%	42%
	2	1	3	4	31	0	8	33	11	4	64	73%	100%
SP	**1**	1	24	11	13	14	10	7	34	25	20	58%	63%
	2	1	19	16	13	11	13	7	32	27	20	54%	63%
WP	**1**	1	5	0	10	15	5	44	10	15	54	40%	25%
	2	1	2	3	10	10	10	44	12	13	54	48%	17%

FIGURE 4.6 COMPARISONS BETWEEN MODEL OUTPUT OF SCUM APPEARANCE (SCUM APPEAR, LINES) AND FIELD SCUM CATEGORIES (POINTS) FOR (A) DELFTSE HOUT, (B) GOOIMEER AND (C) EEMMEER, (D) SLOTERPLAS AND (E) WESTEINDERPLASSEN, 11 JULY TO 5 OCTOBER 2008 BASED ON MODEL SIMULATIONS USING FORECASTED METEOROLOGICAL DATA

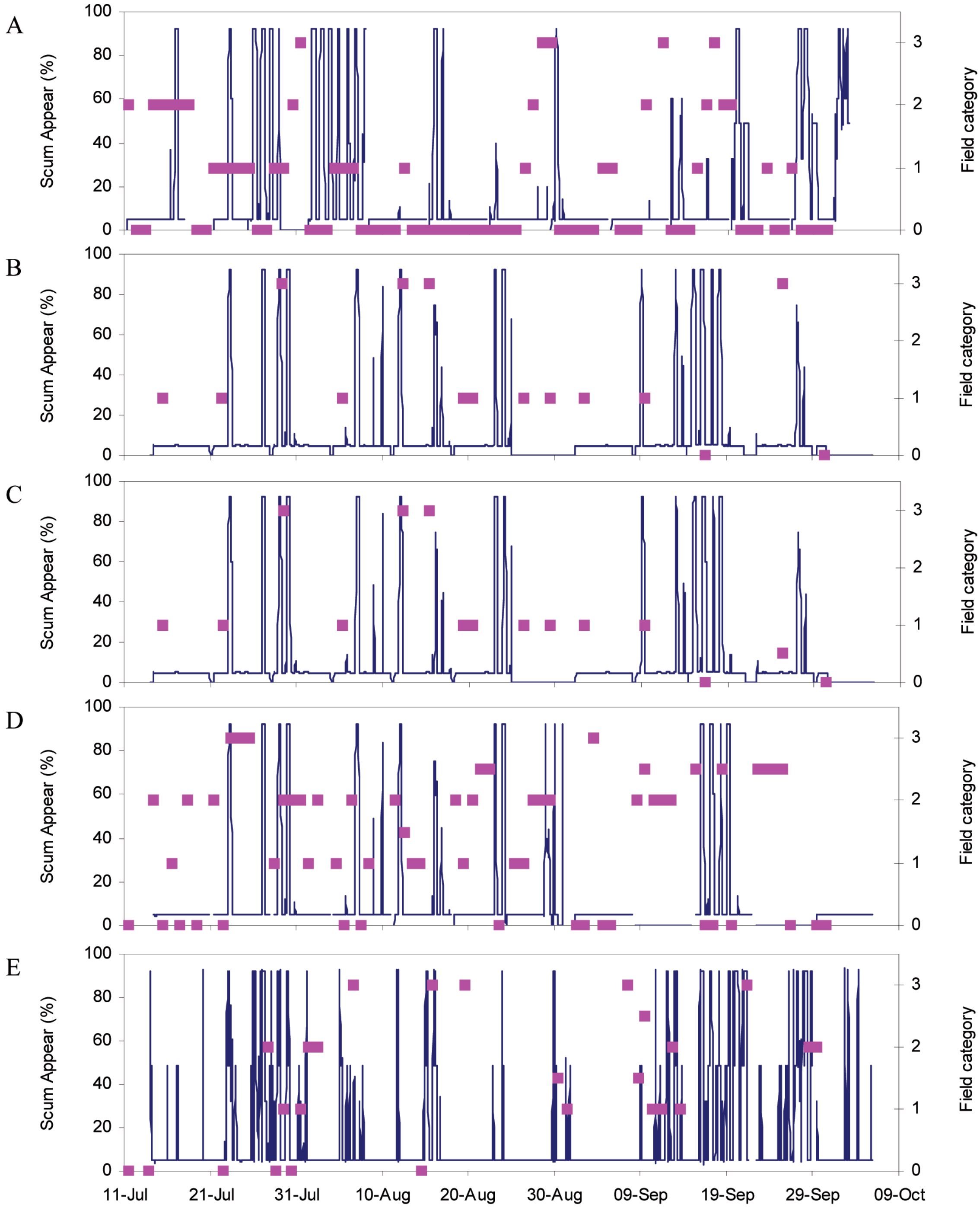
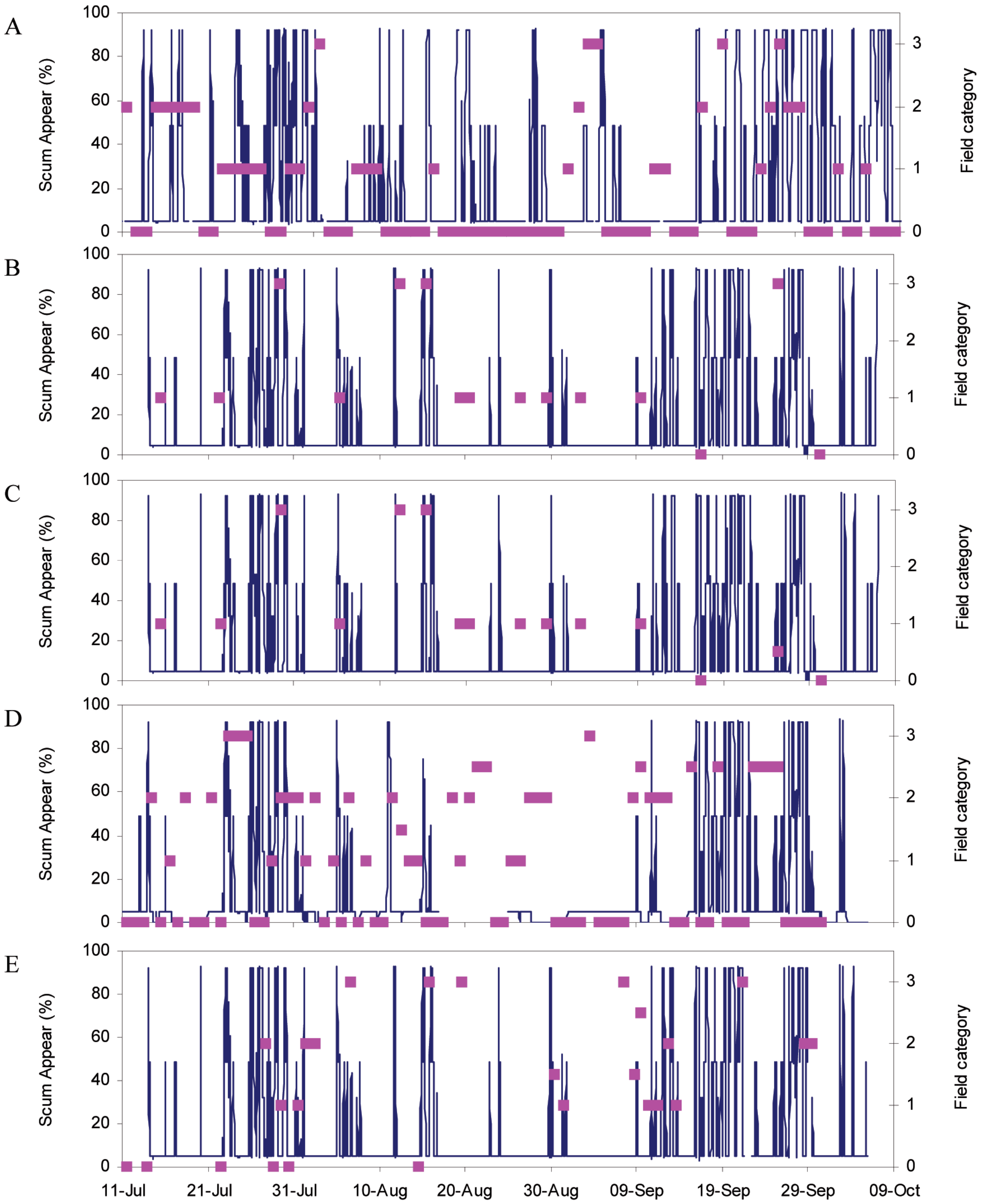


FIGURE 4.7 COMPARISONS BETWEEN MODEL OUTPUT OF SCUM APPEARANCE (SCUM APPEAR, LINE) AND FIELD SCUM CATEGORIES (POINTS) FOR (A) DELFTSE HOUT, (B) GOOIMEER AND (C) EEMMEER, (D) SLOTERPLAS AND (E) WESTEINDERPLASSEN, 11 JULY TO 5 OCTOBER 2008 BASED ON MODEL SIMULATIONS USING OBSERVED METEOROLOGICAL DATA



4.5.1 STATISTICAL ANALYSIS

The results of the Cohen's Kappa test showed that comparisons between model and field data were poor for all lakes except for the Gooimeer and Eemmeer (Table 4.4). The results of the test indicate a moderate to almost perfect agreement between the field data and model output for Gooimeer-Eemmeer, although the field data available for the validation was very limited. For all other lakes the score was no or slight agreement.

TABLE 4.4 SUMMARY OF COHEN'S KAPPA STATISTICAL TEST FOR COMPARISONS BETWEEN MODEL OUTPUT AND FIELD VALIDATION DATA FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR SIMULATIONS CONDUCTED USING FORECASTED AND OBSERVED (HIND CAST) METEOROLOGICAL DATA

Lake	Forecast simulations	Hind cast simulations
DH	< 0 No agreement	0.0 — 0.20 Slight agreement
GM	0.81 — 1.00 Almost perfect agreement	0.61 — 0.80 Substantial agreement
EM	0.81 — 1.00 Almost perfect agreement	0.41 — 0.60 Moderate agreement
SP	< 0 No agreement	0.0 — 0.20 Slight agreement
WP	< 0 No agreement	< 0 No agreement

4.5.2 ANALYSES OF MODEL OUTPUT THRESHOLD

To assess whether the biomass threshold (1 g C m $^{-2}$) used to define a true model scum event also leads to over prediction of scum events, a further analysis was completed to assess whether changing of this threshold leads to an improvement in model scores. In the first instance this analysis was completed only on the Delftse Hout, where the most consistent field validation data is available. The biomass threshold varied from 0.5 to 16 g C m^{-2}, with the model scored based on field category 1 scums or greater as well as field category 2 scums or greater.

The results of this analysis indicate that a lower threshold of 0.5 g C m $^{-2}$ yields the best model scores in terms of both total % correct together and % scums correct for both field scum criteria (1 or greater, or 2 or greater, Table 4.5), although a large number of false positive events still exist. The total model correct could be improved by using very high biomass thresholds (16 g C m^{-2}), but the total scum correct scores decline significantly.

TABLE 4.5 SUMMARY OF MODEL PERFORMANCE FOR THE DELFTSE HOUT OVER THE 2008 SUMMER SIMULATION PERIOD FOR SIMULATIONS CONDUCTED USING OBSERVED METEOROLOGICAL DATA. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. CATEGORY THRES REPRESENTS FIELD CATEGORY APPLIED TO THE MODEL SCORE, BIOMASS THRES MODEL BIOMASS THRESHOLD APPLIED, AND CORRECT AND INCORRECT THE TOTAL ACCURATE AND INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA, RESPECTIVELY, AS A TOTAL OR % OF THE TOTAL

Category thres.	Biomass thres	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Total correct	Total incorrect	ND	% correct	% scums correct
1	0.5	20	10	18	13	12	7	32	23	25	58%	61%
1	1	15	10	17	18	12	8	27	28	25	49%	45%
1	2	13	7	16	20	15	9	28	27	25	51%	39%
1	4	8	5	11	25	17	14	25	30	25	45%	24%
1	8	7	3	9	26	19	16	26	29	25	47%	21%
1	16	2	2	5	31	20	20	22	33	25	40%	6%
2	0.5	12	18	18	4	21	7	33	22	25	60%	75%
2	1	9	16	17	7	23	8	32	23	25	58%	56%
2	2	7	13	16	9	26	9	33	22	25	60%	44%
2	4	6	7	11	10	32	14	38	17	25	69%	38%
2	8	5	5	9	11	34	16	39	16	25	71%	31%
2	16	1	3	5	15	36	20	37	18	25	67%	6%

4.6 FURTHER ANALYSIS DELFTSE HOUT

The model results for the Delftse Hout were examined in more detail to better understand the large mismatch between the field validation data and model output, and to provide insights into methods that could be applied to improve overall model performance. Delftse Hout was chosen as this lake has the most consistent field validation data available over the duration of the study, and is relatively small with only a limited number of shorelines compared to some of the other systems. Special emphasis was placed on:

1 Model false negative events, where the model predicts scum absence while the available field validation data suggests that a scum was present on that day, and;

2 Model false positive events, where the model predicts a scum event that was not observed in the available field data.

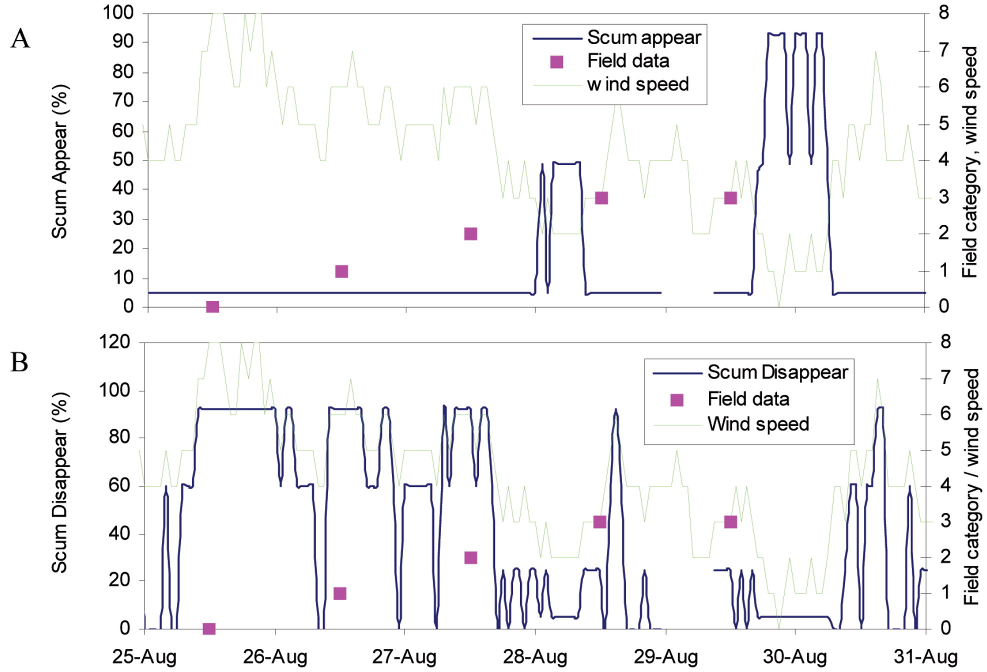
4.6.1 FALSE NEGATIVE EVENTS

For the Delftse Hout, over the period 7 July to 4 October seven false negative events were recorded for model simulations using the observed meteorological data and based on comparisons with the field data using category 2 scums or greater (Table 4.3). These events were analysed in more detail to determine why the model forecasted no scums on these days. The primary reason for the model predictions of scum absence is that the wind speeds are high, often greater than 6 m sec^{-1} (Fig. 4.8). Therefore the model predicts a low scum appearance value, and high scum disappearance value (Fig. 4.8).

TABLE 4.6 SUMMARY OF MODEL FALSE NEGATIVE EVENTS FOR THE DELFTSE HOUT (DH) BETWEEN 14 JULY AND 11 SEPTEMBER 2008. FIELD CATEGORY REPRESENTS FIELD SCUM PRESENCE CATEGORY (RANGE 1-3), MY SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. FOR THE ECOFUZZ PARAMETERS, APPEAR REPRESENTS SCUM APPEARANCE VALUE, DISAP. SCUM DISAPPEARANCE VALUE AND WIND MEAN WIND SPEED (M SEC^{-1})

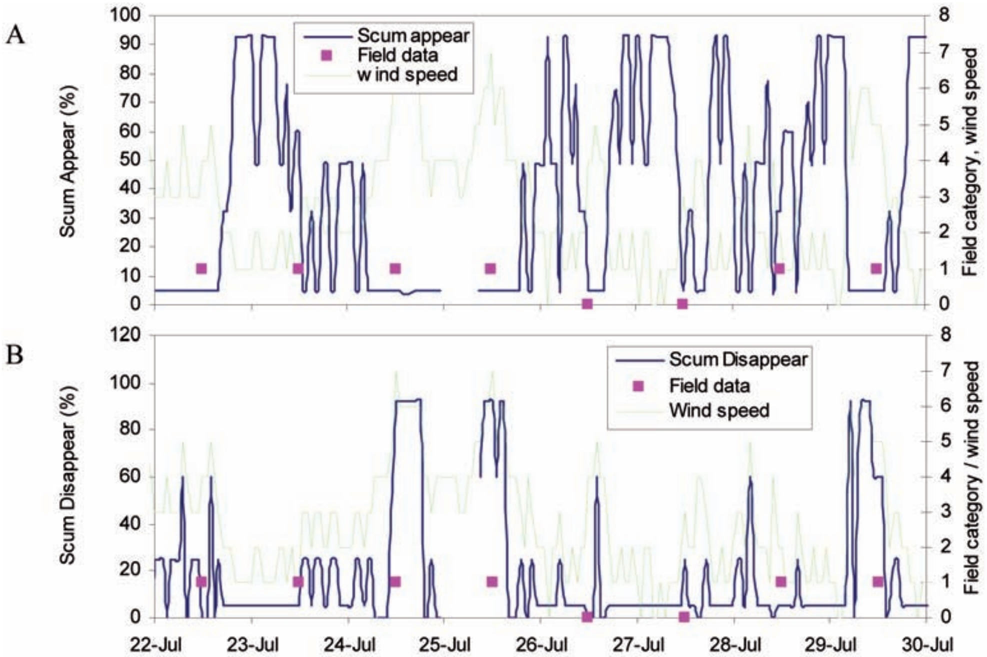
Date	Field category	Model Vs Field MY FY	MY FN	FY MN	MN FN	EcoFuzz Appear	Disap.	Wind	Reason for mismatch
14/07/2008 12:00	2	0	0	1	0	5	93	7	Wind speed too high, appearance low
15/07/2008 12:00	2	0	0	1	0	5	92	6	Wind speed too high, appearance low
18/07/2008 12:00	2	0	0	1	0	5	92	8	Model time step?
31/07/2008 12:00	3	0	0	1	0	5	0	3	Biomass < 1
27/08/2008 12:00	2	0	0	1	0	5	60	6	Wind speed too high, appearance low
29/08/2008 12:00	3	0	0	1	0	49	5	3	Model time step?
11/09/2008 12:00	3	0	0	1	0	49	92	4	Wind speed too high, appearance low

FIGURE 4.8 MODEL OUTPUT FOR (A) SCUM APPEARANCE AND (B) SCUM DISAPPEARANCE, TOGETHER WITH WIND SPEED (M SEC^{-1}) AND FIELD VALIDATION DATA (FIELD CATEGORY), DELFTSE HOUT 25 TO 31 AUGUST 2008



Of the seven no scum events, four were due to the wind speed being too high while two were due to the model time step, with the model restarted with a complete reset two hours before the field validation data was collected.

FIGURE 4.9 MODEL OUTPUT FOR (A) SCUM APPEARANCE AND (B) SCUM DISAPPEARANCE, TOGETHER WITH WIND SPEED (M SEC^{-1}) AND FIELD VALIDATION DATA (FIELD CATEGORY), DELFTSE HOUT 22 TO 30 JULY 2008



4.6.2 FALSE POSITIVE EVENTS

Over the model period 7 July to 4 October 16 false positive events were recorded for model simulations using the observed meteorological data and based on comparisons with the field data using category 2 scums or greater (Table 4.3). All events were further examined in detail to better understand the reason for the large mismatch between the model output and available field validation data (Table 4.6). The reasons for the mismatch are varied, with the most common being low wind speeds to the model and therefore high scum appearance values (6 events, for example Fig. 4.8), and a gradual decline in scum biomass in the model after a scum event while in the field validation data the scum has already disappeared (8 events).

TABLE 4.7 SUMMARY OF MODEL FALSE POSITIVE EVENTS FOR THE DELFTSE HOUT (DH) BETWEEN 23 JULY AND 29 SEPTEMBER 2008. FIELD CATEGORY REPRESENTS FIELD SCUM PRESENCE CATEGORY (RANGE 1-3), MY SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. FOR THE ECOFUZZ PARAMETERS, APPEAR REPRESENTS SCUM APPEARANCE VALUE, DISAP. SCUM DISAPPEARANCE VALUE AND WIND MEAN WIND SPEED (M SEC^{-1})

Date	Field	Model Vs Field				EcoFuzz			Reason for mismatch
	category	MY FY	MY FN	FY MN	MN FN	Appear	Disap.	Wind	
23/07/2008 12:00	1	0	1	0	0	5	25	1	wind low, appearance high
24/07/2008 12:00	1	0	1	0	0	0	0	7	wind low previous time steps (< 2)
28/07/2008 12:00	0	0	1	0	0	5	92	2	wind low, appearance high
6/08/2008 12:00	1	0	1	0	0	5	25	4	wind speed low 1 time step, app, disap slow to respond
7/08/2008 12:00	0	0	1	0	0	0	0	3	wind speed low 1 time step, app, disap slow to respond
8/08/2008 12:00	0	0	1	0	0	5	0	2	Scum declining
12/08/2008 12:00	1	0	1	0	0	5	93	11	Scum declining
15/08/2008 12:00	0	0	1	0	0	5	0	4	Model time step
18/08/2008 12:00	0	0	1	0	0	5	93	7	Low wind speed previous time step, disap slow
22/08/2008 12:00	0	0	1	0	0	5	92	4	Low wind speed previous time step, disap slow
25/08/2008 12:00	0	0	1	0	0	5	92	8	Combination
1/09/2008 12:00	0	0	1	0	0	5	92	8	Uncertain
22/09/2008 12:00	0	0	1	0	0	5	0	4	Scum declining
23/09/2008 12:00	0	0	1	0	0	5	0	4	Scum declining
28/09/2008 12:00	0	0	1	0	0	5	25	3	Scum declining
29/09/2008 12:00	0	0	1	0	0	5	93	3	Scum declining

5

MODEL IMPROVEMENTS AND RECALIBRATION

5.1 INTRODUCTION

Based on the results of the model validation presented at the EWACS-meeting of 30 October 2008, a number of additional research activities were conducted to further refine and calibrate the complete model instrumentation, to improve overall model performance through the reduction of the number of incorrect model scores for each of the four pilot systems. The research activities described in this Chapter are based on the ideas discussed between Deltares and the Steering Committee, and are focused on further development of the model framework through refinement of the processes for scum appearance and disappearance in the model code, the testing of variations in model data input formats to try and reduce the high variations observed in the data (e.g. wind speed), and testing of the EcoFuzz stand alone model for 2006 to test model performance in a year in which cyanobacteria scums were considered to be more problematic than more in recent years.

The research activities examined include:

1. **Model code development:**
   a. EcoFuzz scum appearance and disappearance calculated per grid cell as a function of the wind multiplication factor specified along the lake shorelines.
   b. Variation of the wind multiplication factor (currently set to 0 or 1) using the new approach in 1a above and to test the model with a wind multiplication of 0.5 (less wind if shoreline is sheltered) or some other values to test if this has an effect.
   c. Variation of wind multiplication factor based on wind cards determined by water boards.
   d. Further examination of the process as a whole (brain storm within Deltares to see if we can further improve the processes and how they are implemented in the model once all model changes and testing has been carried out).
2. **Model input data:**
   b. Light input: testing of various light input time lags (to incorporate historical light climate), including:
      i. -12 hr, -24 hr, -48 hr lag (delayed response time to light)
      ii. average of 0 and -24 hr lag
      iii. average of 0, -24 and -48 hr lag
      iV. average of 0, -24, -48 and -72 hr, 1 week lag
   b. Wind speed input:
      i. Test model with scaled wind speeds (for example 20% reduction in wind). Wind speeds changed in input file and not in membership functions in first instance.
      ii. Test model with minimum and maximum wind speeds (for example max of last 6 hours):
      iii Wind speed membership function: Further calibration of membership functions for wind speed if reductions in wind speeds are considered promising (changing wind speed thresholds in membership function for appearance and disappearance rather than scaling wind speed input)

c. Wind speed: further calibration of membership functions for wind speed if Part 2.a and 2.b results are considered promising (changing wind speed thresholds in membership function for appearance and disappearance rather than scaling wind speed input).

3. **EcoFuzz stand alone model 2006:**
   a. The EcoFuzz model in stand alone mode using 2006 climate data to examine model performance in a high cyano year. Model output to be compared to any data the water boards have regarding lake closures.

5.2 MODEL CODE DEVELOPMENT AND TESTING

5.2.1 CHANGES TO MODEL CODE AND SETUP

To better simulate likely spatial variations in scum appearance and disappearance associated with differences in wind shelter within a lake, the model code was altered to incorporate grid cell and wind direction specific wind speeds to the scum appearance and disappearance processes. While EcoFuzz appearance and disappearance is currently calculated for every grid cell in the model schematization, inputs of wind speed for the appearance and disappearance routines are identical for all cells. Therefore in the current model setup, calculations of scum appearance and disappearance are nearly identical for all cells modelled, unless cyanobacterial biomass in a particular grid cell is below the predefined cyanobacterial threshold as biomass may vary due to horizontal transport within the system.

The horizontal scum transport routine currently implemented in the model uses cell-specific wind speed multiplication factors for eight different wind directions to prevent the horizontal transport of scum out of wind sheltered shorelines. However, the scum disappearance routine can lead to the disappearance of persistent surface scums regardless of wind speed or grid cell location, as wind speed inputs to this process are identical for all cells.

To better model persistent cyanobacterial scums, the scum appearance and disappearance routines were coupled to wind speed calculated for the horizontal scum transport routines. In this new approach, scum appearance and disappearance are truly grid cell specific, with the wind speed used as input to these routines dependent on wind direction and the location of the cell relative to lake shorelines. In addition to the changes implemented in the model code, a number of further revisions were tested and carried out before the new model code was applied to all lakes for the entire model simulation period. These included:

* The reduction of the scum appearance (value 40) and scum disappearance (value 80) thresholds to zero given that scum appearance and disappearance processes are now grid-cell specific in the new modelling approach.
* The wind drag coefficient used to regulate horizontal scum transport was reduced from 1 to 0.02 following detailed examination of the flow model output, given that the wind induced flow velocity should be approximately to 2% or 3% of the wind velocity.
* To reduce high variations observed in the model output of cyanobacterial scum appearance and disappearance (e.g. Fig. 1.4). In addition, based on the idea that the system does not respond instantaneously to fluctuations in the wind speed, the wind velocity and direction used as input to the scum model was based on daily averages rather than hourly data.

The new model code was first tested in the Delftse Hout over two simulation periods (Weeks 36 & 37 of 2008), to examine model performance and ensure that the model code changes did result in a change in model output relative to the previous approach. Comparisons between the existing and new model clearly show that simulations of scum appearance (Fig. 5.1) and scum disappearance (Fig. 5.2) are now grid cell specific in the new model. Further, simulations of cyanobacterial surface scum biomass are now also different compared to the existing model (Fig. 5.3).

Comparisons between the existing and new model codes in the Delftse Hout over the period 6 to 18 September 2008 indicate that the results for scum appearance and disappearance are much less variable on short time scales (Fig. 5.4), resulting in much more gradual change in cyanobacterial scum biomass compared to the previous modelling approach, although the timing of scum events between the two models remains similar. Simulations of scum biomass are now also very different between different locations in the lake compared to the existing model where trends between locations were much more similar (Figs. 5.5 – 5.7).

FIGURE 5.1 COMPARISONS OF MODEL OUTPUT FOR SCUM APPEARANCE BETWEEN THE (TOP) EXISTING MODEL AND (BOTTOM) REVISED MODEL CODE, DELFTSE HOUT, 8 SEPTEMBER 2008. VALUES OF 100 (YELLOW) REPRESENT HIGH SCUM APPEARANCE AND BLUE (0) NO SCUM APPEARANCE

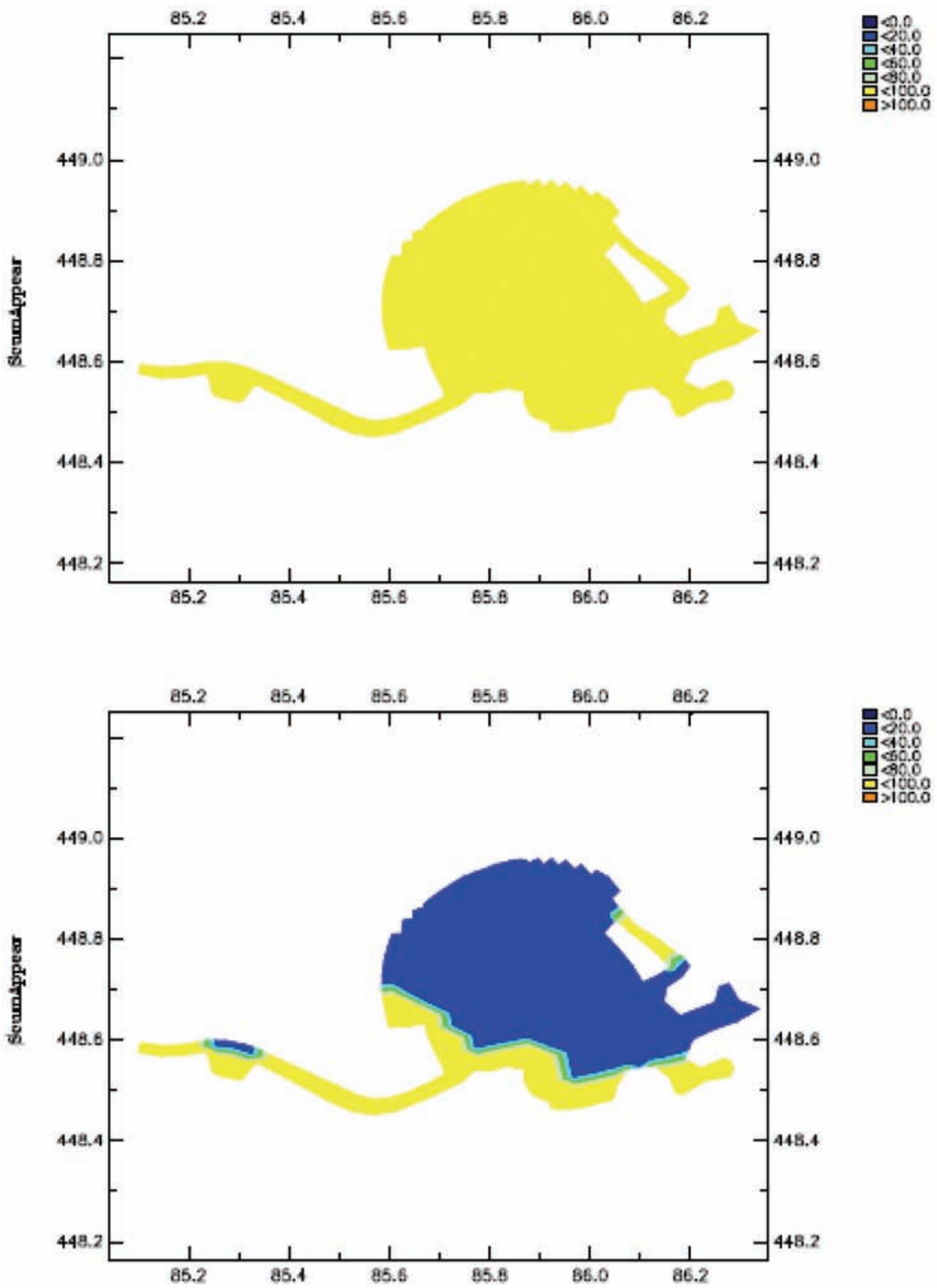


FIGURE 5.2 COMPARISONS OF MODEL OUTPUT FOR SCUM DISAPPEARANCE BETWEEN THE (TOP) EXISTING MODEL AND (BOTTOM) REVISED MODEL CODE, DELFTSE HOUT, 8 SEPTEMBER 2008. VALUES OF 100 (YELLOW) REPRESENT HIGH SCUM DISAPPEARANCE AND BLUE (0) NO SCUM DISAPPEARANCE

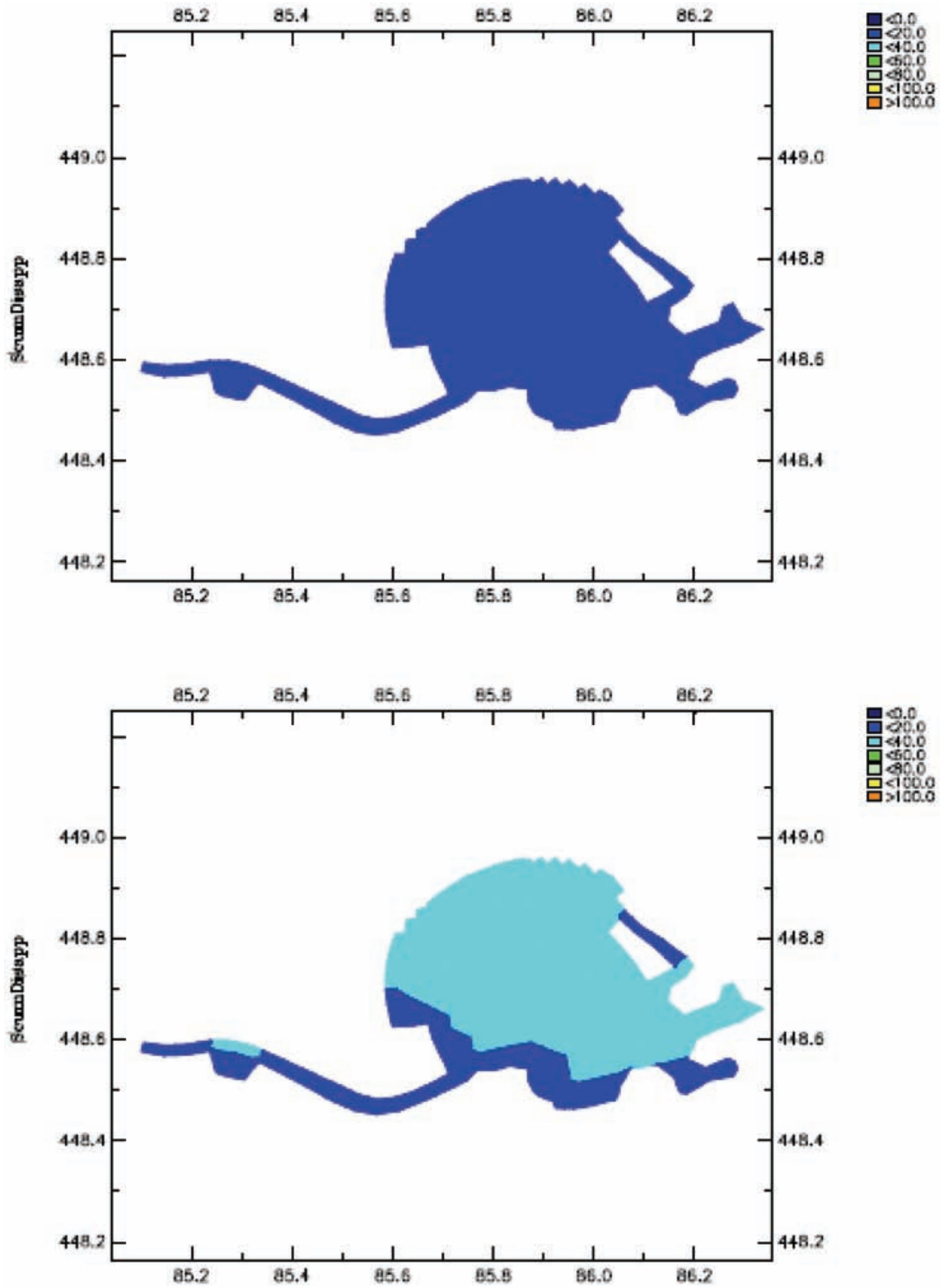


FIGURE 5.3 COMPARISONS OF MODEL OUTPUT FOR SCUM BIOMASS (G C M^2) BETWEEN THE (TOP) EXISTING MODEL AND (BOTTOM) REVISED MODEL CODE, DELFTSE HOUT, 8 SEPTEMBER 2008. VALUES GREATER THAN 1.2 (RED) REPRESENT HIGH SCUM BIOMASS

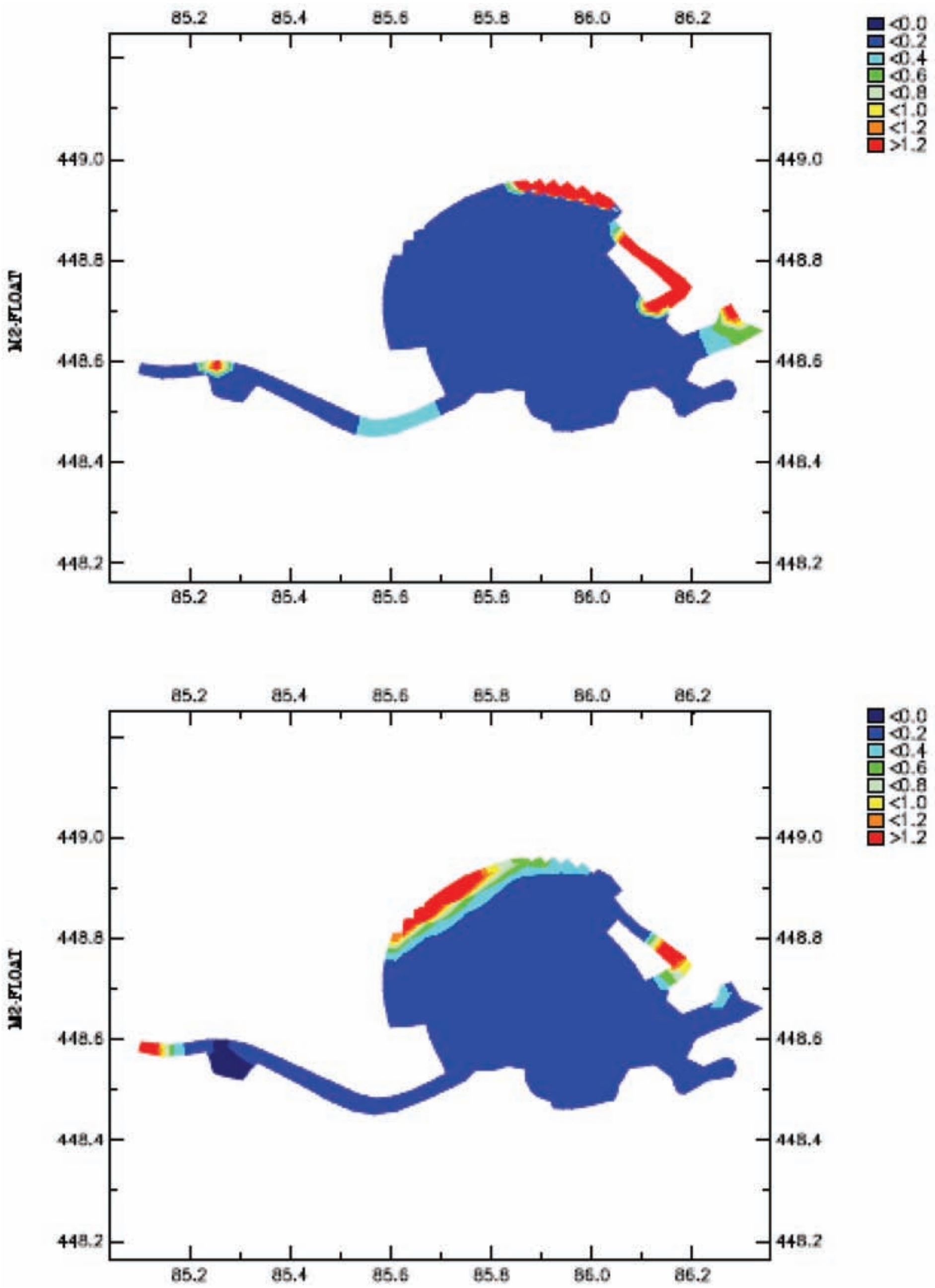


FIGURE 5.4 COMPARISONS OF EXISTING (OLD METHOD) AND REVISED (NEW METHOD) MODEL OUTPUT FOR (TOP) SCUM APPEARANCE, (MIDDLE) SCUM DISAPPEARANCE AND (BOTTOM) SCUM BIOMASS FOR LOCATION 4 (EASTERN SHORELINE), DELFTSE HOUT, 6 - 18 SEPTEMBER 2008

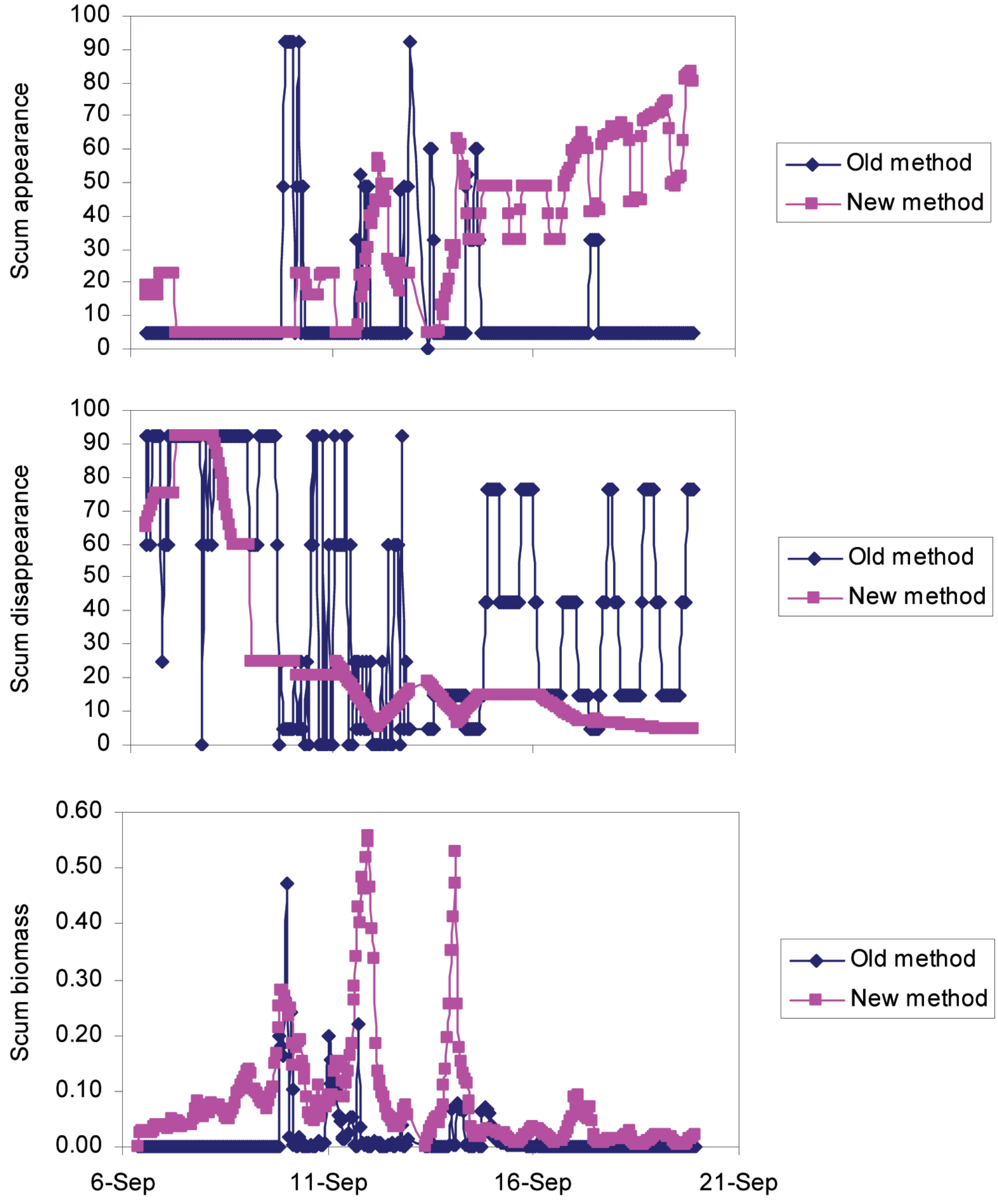


FIGURE 5.5 COMPARISONS OF EXISTING (OLD METHOD) AND REVISED (NEW METHOD) MODEL OUTPUT FOR (TOP) SCUM APPEARANCE, (MIDDLE) SCUM DISAPPEARANCE AND (BOTTOM) SCUM BIOMASS FOR LOCATION 5 (NORTH EASTERN SHORELINE), DELFTSE HOUT, 6 - 18 SEPTEMBER 2008

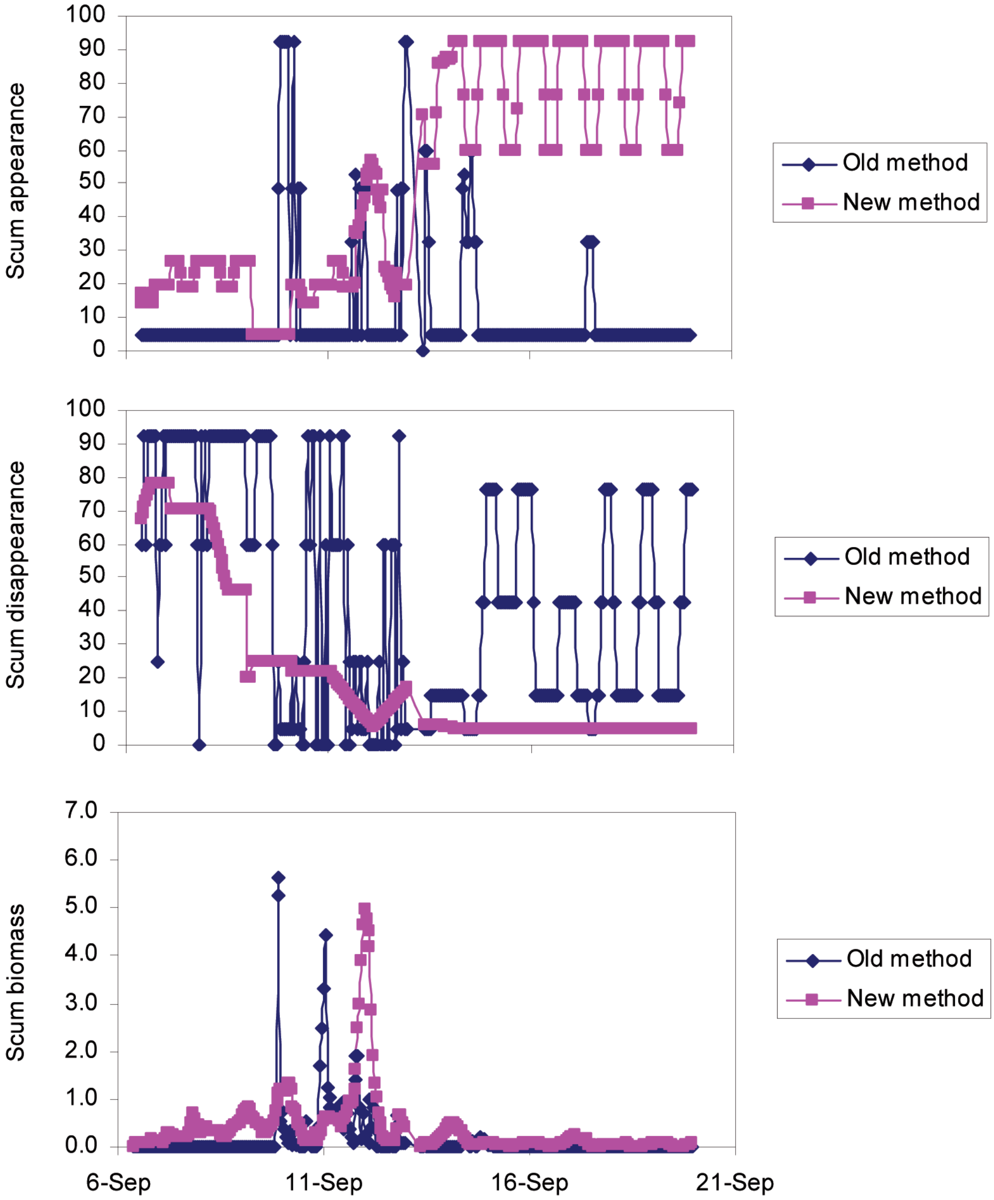
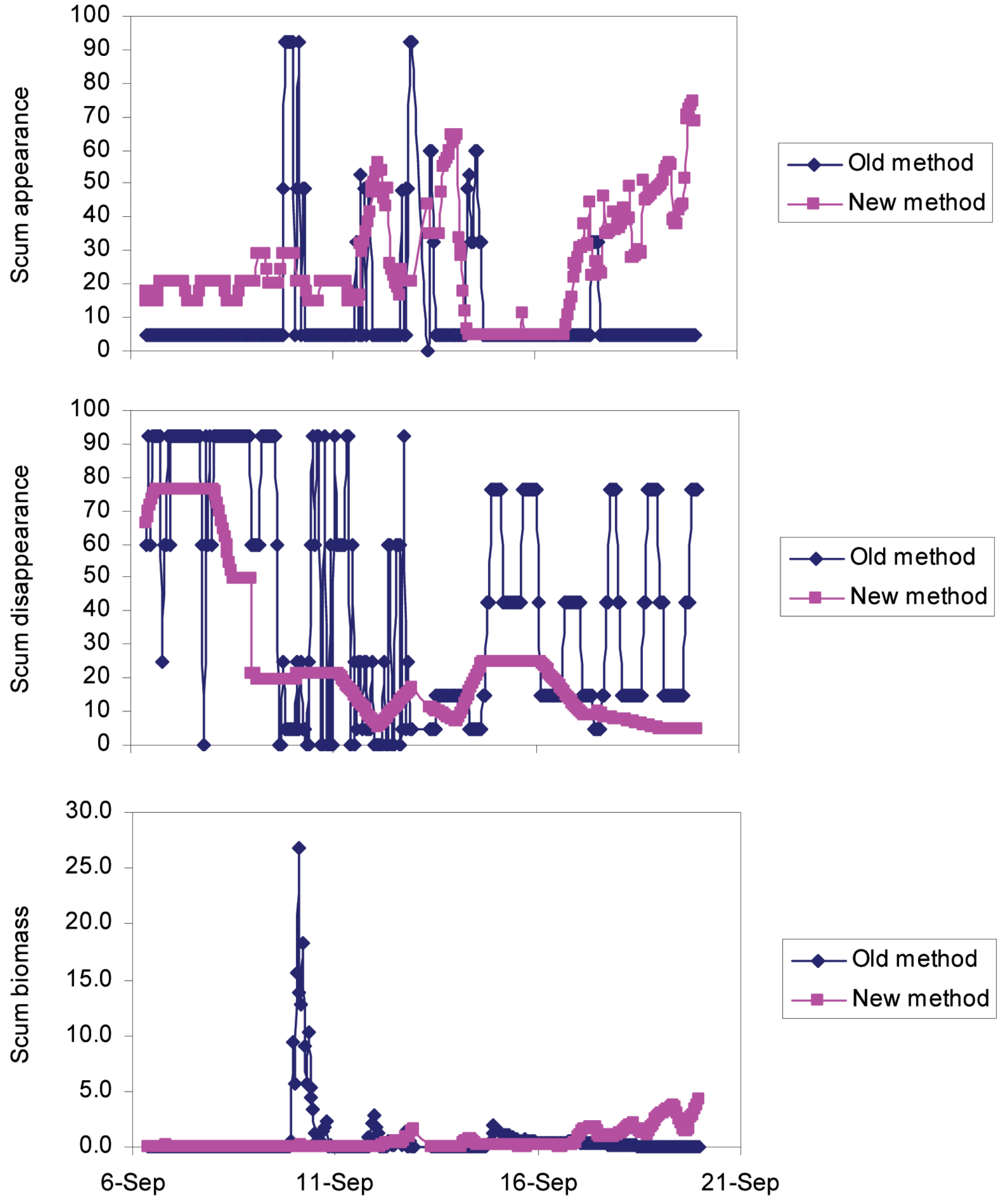


FIGURE 5.6 COMPARISONS OF EXISTING (OLD METHOD) AND REVISED (NEW METHOD) MODEL OUTPUT FOR (TOP) SCUM APPEARANCE, (MIDDLE) SCUM DISAPPEARANCE AND (BOTTOM) SCUM BIOMASS FOR LOCATION 6 (NORTH WESTERN SHORELINE), DELFTSE HOUT, 6 - 18 SEPTEMBER 2008



5.2.2 MODEL RESULTS REVISED CODE ALL SYSTEMS

The revised model code and additional revisions to the model input data and scum appearance and disappearance thresholds were applied to all four pilot systems over the full 2008 summer period. Model output for scum biomass was scored based on the existing methodology applied. In this assessment, the maximum biomass of surface scum forming cyanobacteria of all aggregated zones were compared to the field data to see on which days the lake wide model predictions were correct. Given the potential differences in daily field data collection times, the model maximum biomass over a 2 hour period immediately before and after midday was used for the comparisons. A threshold of 0.5 g C m^2 cyano was applied to differentiate between a true and non model scum events and the model was scored using field category 1 (Table 5.1) or greater as well as field category 2 or greater (Table 5.2) to represent true field scum events. The results of this analysis are plotted in Figures 5.7 and 5.8.

Delftse Hout

The revised model led to little change in the total model score (-2%) compared to the existing model simulations, although the total number of scums predicted accurately increased from 61% to 85% when all field scums of category 1 or greater and low model biomass thresholds (0.5 g C m^2) are applied (Table 5.1). An increase in the total number of false positive events (+ 9 events) in the revised modelling approach was offset by a decrease in false negative events (- 8 events).

When category 2 scums were applied the model score decreased relative to the original score, from 60% total correct to 29% total correct, due to a large increase in false positive predictions, although the total number of scums predicted correctly by both models were identical (75%) between the two model runs (Table 5.2).

Gooimeer-Eemmeer

The revised model results led to an increase in the total model score (+ 10%), and no change in the total number of scums predicted (75%), compared to the exiting model for Lake Gooimeer (Table 5.1). For Lake Eemmeer, the revised model led to a decrease in both total model correct (-26%) and total scums correct (-25%), although only 3 scums were validated in the lake over the summer period and the total model score for scums still remains high (75%).

Sloterplas

For the Sloterplas the revised model led to a 16% decline in the total model correct score, with no scum events predicated accurately due to the large increase in false negative events (Table 5.1). While the scums do occur in the model output, the scum biomass is very low in the model output (Fig. 5.8).

Further analysis of the Sloterplas results including testing of the model time step and thresholds used for the scoring process indicated that the low biomass accumulation is due to a combination of factors. The phytoplankton biovolume in the lake was low relative to the Delftse Hout, Gooimeer and Eemmeer (Fig. 3.3) and the surface area of open water in the lake from which the accumulated cells derive from is also low compared to most of the other systems. Finally, the Sloterplas is a much deeper system, and cells mixed through the water column take longer to reach the surface waters, often by which time the disappearance routines have already started. A reduction in model time step from 1 hour to 5 minutes increased the biomass slightly.

Collectively, the results suggest that the spatial aggregation does not work well for these deeper lakes, and therefore that the biomass threshold used to score the model should be set much lower for this system, for example to 0.01 g C m^2 cyano. When this threshold was applied, the total number of scums predicted correctly was around 53% total correct when using both field category 1 or greater and category 2 or greater, with the total cyanobacterial scums correct being 44% and 38%, respectively.

Westeinderplassen

Model scores for total correct increased from 44% to a total of 48% correct in the Westeinderplassen for the new simulations compared to the existing model (Table 5.1). The total number of accurate scum predictions also increased from 25% to 50% correct.

TABLE 5.1 SUMMARY OF MODEL PERFORMANCE FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR THE EXISTING MODEL RESULTS AND REVISED MODEL RESULTS BASED ON FIELD CATEGORY 1 AND MODEL SCUM BIOMASS OUTPUT 0.5. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT

	Lake	Scums	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Total correct	Total incorrect	ND	% correct	% scums correct
Existing model	DH	33	20	10	18	13	12	7	32	23	25	58%	61%
	GM	13	6	1	40	7	1	24	7	8	64	47%	46%
	EM	12	5	2	31	7	1	33	6	9	64	40%	42%
	SP	38	24	11	13	14	10	7	34	25	20	58%	63%
	WP	20	7	1	12	13	4	42	11	14	54	44%	35%
Revised model	DH	33	28	19	24	5	3	1	31	24	25	56%	85%
	GM	13	3	1	17	10	1	47	4	11	64	27%	23%
	EM	12	8	1	29	4	2	35	10	5	64	67%	67%
	SP	44	0	0	0	44	23	20	23	44	20	34%	0%
	WP	20	8	5	28	12	0	26	8	17	54	32%	40%

TABLE 5.2 SUMMARY OF MODEL PERFORMANCE FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR THE EXISTING MODEL RESULTS AND REVISED MODEL RESULTS BASED ON FIELD CATEGORY 2 AND MODEL SCUM BIOMASS OUTPUT 0.5. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT

	Lake	Scums	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Total correct	Total incorrect	ND	% correct	% scums correct
Existing model	DH	16	12	18	18	4	21	7	33	22	25	60%	75%
	GM	4	3	4	1	1	7	24	10	5	25	67%	75%
	EM	3	3	4	0	0	8	33	11	4	33	73%	100%
	SP	30	19	16	11	11	13	7	32	27	18	54%	63%
	WP	12	3	5	12	9	8	42	11	14	54	44%	25%
Revised model	DH	16	12	35	24	4	4	1	16	39	25	29%	75%
	GM	4	3	1	17	1	10	47	13	2	64	87%	75%
	EM	3	2	7	29	1	5	35	7	8	64	47%	67%
	SP	33	0	0	0	33	34	20	34	33	20	51%	0%
	WP	12	6	7	28	6	6	26	12	13	54	48%	50%

Statistical analysis

The results of the Cohen's Kappa test suggest that comparisons between model and field data were poor for all lakes based on the revised model, except for the Gooimeer (Table 5.3). Results of the test indicate a substantial agreement between the field data and model output for Gooimeer, although the field data available for the validation was very limited. For all other lakes the score was no or slight agreement

TABLE 5.3 SUMMARY OF COHEN'S KAPPA STATISTICAL TEST FOR COMPARISONS BETWEEN MODEL OUTPUT AND FIELD VALIDATION DATA FOR THE DELFTSE HOUT (DH), GOOIMEER (GM), EEMMEER (EM), SLOTERPLAS (SP) AND WESTEINDERPLASSEN (WP) OVER THE 2008 SUMMER SIMULATION PERIOD FOR OUTPUT BASED ON FIELD SCUM CATEGORY 2 AND FIELD SCUM CATEGORY 1

	Lake	Old model	Revised model
Field category 2, Biomass threshold 0.5	DH	0.21 — 0.40 Fair agreement	< 0 No agreement
	GM	0.21 — 0.40 Fair agreement	0.61 — 0.80 Substantial agreement
	EM	0.41 — 0.60 Moderate agreement	0.0 — 0.20 Slight agreement
	SP	0.0 — 0.20 Slight agreement	< 0 No agreement
	WP	< 0 No agreement	< 0 No agreement
Field category 1, Biomass threshold 0.5	DH	0.0 — 0.20 Slight agreement	< 0 No agreement
	GM	< 0 No agreement	< 0 No agreement
	EM	< 0 No agreement	0.21 — 0.40 Fair agreement
	SP	0.0 — 0.20 Slight agreement	< 0 No agreement
	WP	0.0 — 0.20 Slight agreement	< 0 No agreement

Horizontal distribution of scums

The model results were also scored based on comparisons between the location of model scum output and the location where scums were observed in the field data. The total number of validation and model aggregation zones varied per lake system, from 12 locations in the Delftse Hout to 20, 37 and 60 locations in the Sloterplas, Westeinderplassen and Gooimeer-Eemmeer, respectively.

For the Delftse Hout, horizontal model scores were low, with cyanobacterial scums predicted on the right day and for the right location on only 13 out of 33 events for category 1 scums or greater, and 7 out of 16 events for category 2 scums or greater, compared to the available field validation data. The new modelling approach did lead to an improvement in model scores relative to the previous simulations, with an increase of 60% for category 1 or greater and 40% for category 2 or greater.

For the Gooimeer and Eemmeer, the model accurately predicted the timing and location of scums 50% of the time for category 2 scums or greater, although the amount of validation events available was too low (4) to assess this more fully. Scores for both the Westeinderplassen and Sloterplas were poor for the location of the model scum relative to the field data.

FIGURE 5.7 COMPARISONS BETWEEN MODEL OUTPUT OF SCUM FORMING CYANOBACTERIAL BIOMASS (SCUM BIOMASS) AND FIELD SCUM CATEGORIES FOR (A) DELFTSE HOUT, (B) GOOIMEER AND (C) EEMMEER, 1 JULY TO 30 SEPTEMBER 2008. NOTE MODEL SIMULATIONS FOR THE DELFTSE HOUT COMMENCED ON 7 JULY AND FOR GOOIMEER AN EEMMEER 14 JULY

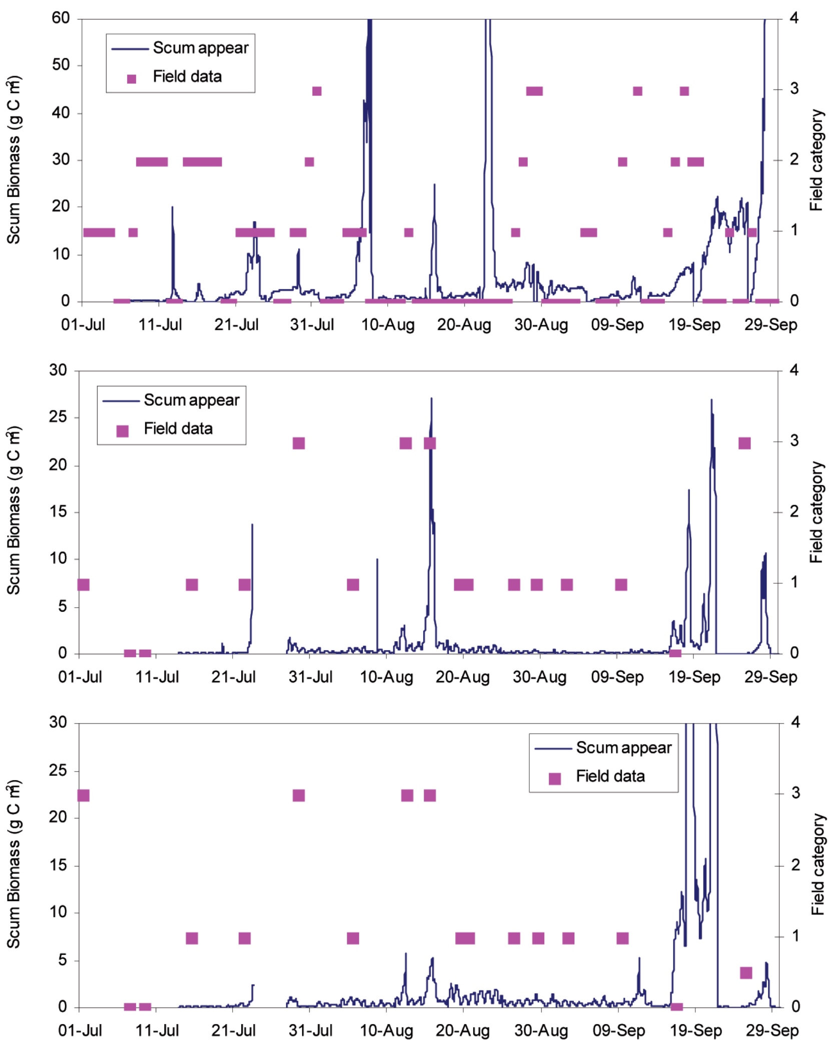
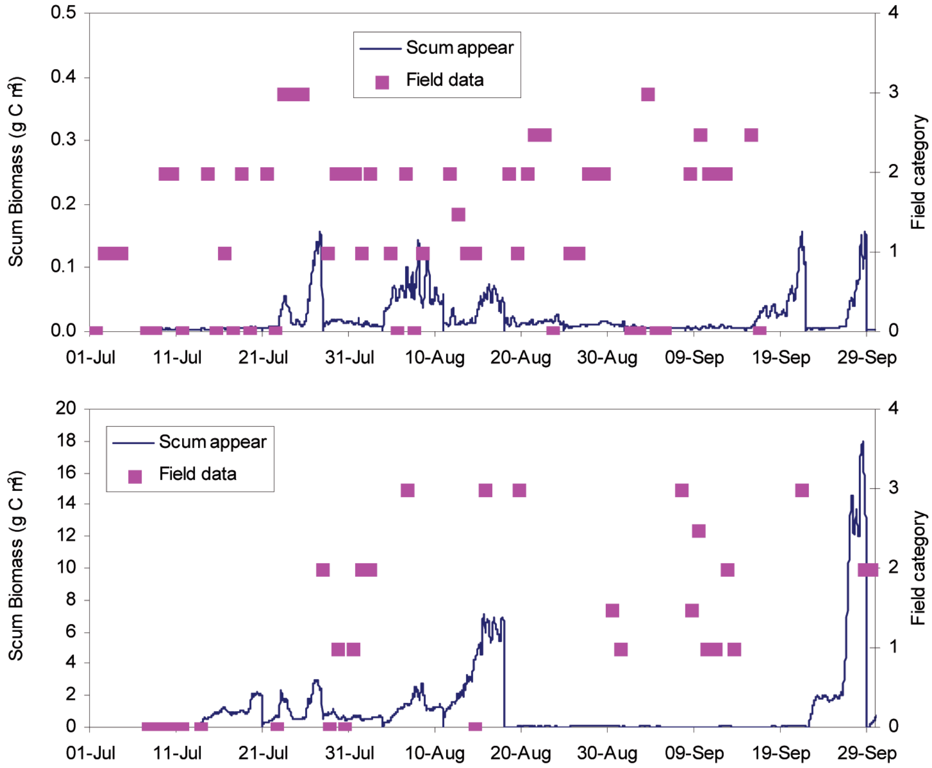


FIGURE 5.8 COMPARISONS BETWEEN MODEL OUTPUT OF SCUM FORMING CYANOBACTERIAL BIOMASS (SCUM BIOMASS) AND FIELD SCUM CATEGORIES FOR (A) SLOTERPLAS AND (B) WESTEINDERPLASSEN, 1 JULY TO 30 SEPTEMBER 2008. NOTE MODEL SIMULATIONS FOR THE SLOTERPLAS COMMENCED ON 7 JULY AND FOR THE WESTEINDERPLASSEN ON 14 JULY



5.2.3 VARIATION OF THE WIND MULTIPLICATION FACTOR

The cell specific wind multiplication factor for eight different wind directions used to in the model processes for scum appearance, disappearance and horizontal transport to differentiate between wind sheltered and non sheltered locations in the lake is currently set to values of zero (wind sheltered for a particular wind direction) or 1 (not sheltered). It was the intention as part of this study to examine differences in the magnitude of the wind multiplication factor, associated with differences in the degree of wind shelter along different lake shorelines.

Based on the results obtained in Section 5.2.2, the option of varying the wind multiplication factor was not considered to lead to a further overall improvement in the model results, due to low model scores predicted for both the timing and location of the model scums compared to the field data for most systems, and the large number of zones and limited validation data available for the larger systems, meaning that any improvements in the model will be difficult to determine and quantify.

Model input data

Additional model runs were completed to test variations in the input data for the EcoFuzz module to try and better understand the model sensitivity to the input data and to improve overall model performance for the timing of scum events. The scenarios tested focused on variations in solar radiation, and reductions in wind speed. In the first instance six scenarios for light and one for wind speed were trialled over a one-two week period in the Delftse Hout (5 – 18 September), coinciding with a period when a large number of scums of category 2 or greater were observed in the field. The scenarios conducted were:

1 Light:
   a. 12 hr, 24 hr 48 hr and 72 hr delays in light input
   b. average of 0 and -24 hr time lag
   c. average of 0, -24 and -48 hr time lag
   d. average of 0, -24, -48 and -72 hr time lag
2 Wind speed input:
   a. 20% reduction in wind speed in the first instance

The use of further variations in wind speed data input was already partly tested in Section 1.2 through the implementation of mean daily wind rather than hourly values to better represent the likely much slower response of the system to changes in to reduce high variations observed in model output of cyanobacterial scum appearance and disappearance observed in the current model output and based on the idea that the system does not respond instantaneously to fluctuations in the wind speed.

All scenarios were made based on the model code changes implemented and tested in Section 5.2. The results of the simulations were compared to the revised model simulations without the reductions in wind speed or light time lags in Section 5.2. Model output was compared for scum appearance and scum disappearance at a central lake location, as well as surface scum biomass along all shorelines in the Delftse Hout.

5.2.4 RESULTS LIGHT SCENARIOS

The results of the 12, 24, 48 and 72 hour light time lag scenarios suggest that there is little difference in the timing of scum events compared to the existing model results, although the degree of appearance is different on some days (Fig. 5.9). For scum disappearance, the timing of the results is also very similar between the scenarios, with variability of up to 20% from the current situation at times (Fig. 5.9). Concentrations of surface cyanobacterial biomass, which represent the combined product of scum appearance and disappearance in the model, were higher for the scenarios with higher scum appearance outputs (time lag scenario 12 and 24 hours), although the timing of scum events was identical between the simulations (Fig. 5.9).

TABLE 5.4 SUMMARY OF DAILY MODEL PERFORMANCE FOR THE DELFTSE HOUT OVER THE 2-WEEK SIMULATION PERIOD 5-18 SEP. 2008 FOR THE EXISTING MODEL RESULTS AND A NUMBER OF SCENARIOS AS DESCRIBED IN SECTION 5.3. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. INCORRECT REPRESENTS THE TOTAL INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA. ONLY FIELD CATEGORIES GREATER THAN OR EQUAL TO CATEGORY 2 ARE CONSIDERED IN THE ANALYSES.

Scenario	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Correct	Incorrect
Existing model	**6**	2	1	0	**2**	4	**8**	2
Light less 12 hr	**6**	2	1	0	**2**	4	**8**	2
Light less 24 hr	**6**	2	1	0	**2**	4	**8**	2
Light less 48 hr	**6**	2	1	0	**2**	4	**8**	2
Light less 72 hr	**6**	2	1	0	**2**	4	**8**	2
Wind less 20%	6	2	3	0	2	2	**8**	2

Model performance relative to the field validation data available was scored for all scenarios based on the existing methods applied. The results, presented in Table 5.4, show that the model scores remain unchanged from the existing model simulations for all light scenarios tested. The results of the mean light time lag scenarios (mean of 0 & 24, 0 & 24 & 48, 0 &

24 & 48 & 72) show identical results for scum appearance, scum disappearance and surface cyanobacterial biomass relative to the exiting model results (Fig. 5.10). As for the previous light scenarios, there was also no change in the overall model results relative to the field validation data (Table 5.5).

TABLE 5.5 SUMMARY OF DAILY MODEL PERFORMANCE FOR THE DELFTSE HOUT OVER THE 2-WEEK SIMULATION PERIOD 12-18 SEP. 2008 FOR THE EXISTING MODEL RESULTS AND A NUMBER OF SCENARIOS AS DESCRIBED IN SECTION 5.3. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. INCORRECT REPRESENTS THE TOTAL INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA. ONLY FIELD CATEGORIES GREATER THAN OR EQUAL TO CATEGORY 2 ARE CONSIDERED IN THE ANALYSES.

Scenario	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Correct	Incorrect
Existing model	**4**	1	0	0	**1**	2	**5**	1
Light mean 0, 24 hr	**4**	1	0	0	**1**	2	**5**	1
Light mean 0, 24, 48 hr	**4**	1	0	0	**1**	2	**5**	1
Light mean 0, 24, 48, 72 hr	**4**	1	0	0	**1**	2	**5**	1

FIGURE 5.9 MODEL OUTPUT OF (A) SCUM APPEARANCE, (B) SCUM DISAPPEARANCE, (C) SCUM BIOMASS AT LOCATION 4 (NORTHERN SHORELINE) AND (D) SCUM BIOMASS AT LOCATION 5 (EASTERN SHORELINE) FOR SIMULATIONS IF THE EXISTING MODEL AND SCENARIOS OF LIGHT TIME LAGS (12, 24, 48 AND 72 HR TIME LAGS), DELFTSE HOUT, 5 – 18 SEPTEMBER 2008

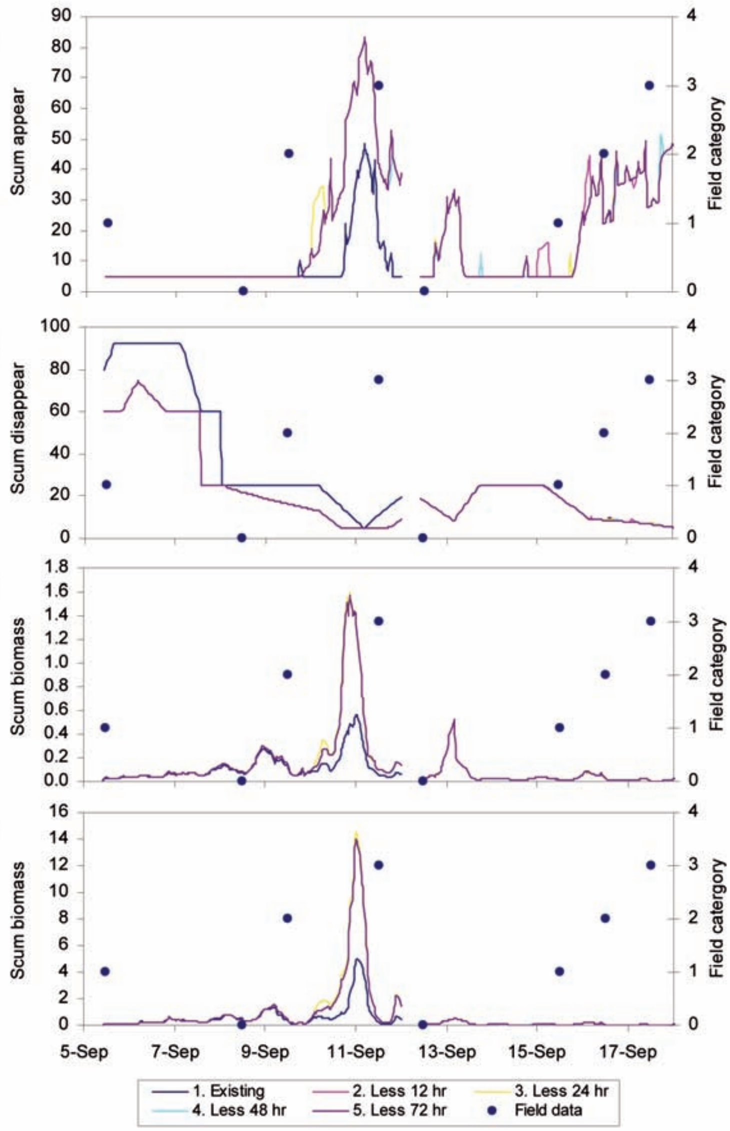
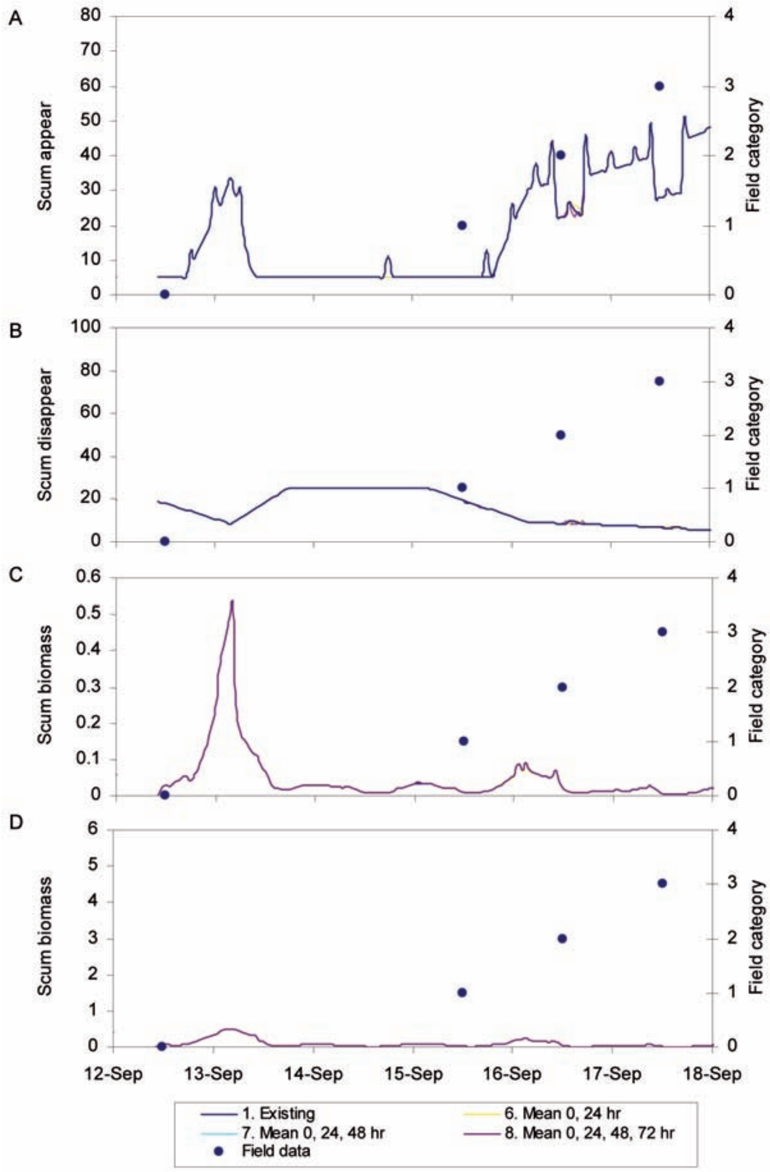


FIGURE 5.10 MODEL OUTPUT OF (A) SCUM APPEARANCE, (B) SCUM DISAPPEARANCE, (C) SCUM BIOMASS AT LOCATION 4 (NORTHERN SHORELINE) AND (D) SCUM BIOMASS AT LOCATION 5 (EASTERN SHORELINE) FOR SIMULATIONS IF THE EXISTING MODEL AND SCENARIOS OF LIGHT TIME LAGS (MEAN OF 0, 24, 48 AND 72 HR TIME LAGS), DELFTSE HOUT, 5 – 18 SEPTEMBER 2008



5.2.5 RESULTS WIND SPEED REDUCTION SCENARIOS

A 20% reduction in wind speed leads to a large increase in model output for scum biomass compared to the existing model simulations (Fig. 5.11), due to a large increase in biomass which was due to the much higher values of scum appearance. While the timing of scum appearance commenced a few hours earlier on some days then on the existing situation, the overall timing of scum biomass peaks was largely unchanged between the model scenarios.

Results of the model scores, as shown in Table 5.4, demonstrate that there is little change in model output for the 20% wind reduction scenario compared to the existing situation. The number of days on which a scum was predicted by the model increased by one during the two week simulation period, although there was no field data available on this day to validate the model results.

To further examine the effects of wind reduction over a much longer time period, model runs were repeated for the entire simulation period for the Delftse Hout (July – Sep. 2008). The results demonstrate that there is little difference in the model output for scum biomass between the existing model and scenarios with the wind reduced by 20% (Fig. 5.12). With the wind reduction, the total number of correctly forecasted days relative to the available field data decreased by 2 (Table 5.6), due to a slight increase in the number of false positive events forecasted.

TABLE 5.6 SUMMARY OF DAILY MODEL PERFORMANCE FOR THE DELFTSE HOUT OVER THE SIMULATION PERIOD JUL.-SEP. 2008 FOR THE EXISTING MODEL RESULTS AND A SCENARIO OF 20% WIND REDUCTION. MY REPRESENTS SCUM PRESENT IN MODEL, FY SCUM PRESENT IN FIELD, MN NO SCUM PRESENT IN MODEL, FN NO SCUM PRESENT IN FIELD AND ND NO VALIDATION DATA PRESENT. INCORRECT REPRESENTS THE TOTAL INACCURATE PREDICTIONS RELATIVE TO THE FIELD DATA. ONLY FIELD CATEGORIES GREATER THAN OR EQUAL TO CATEGORY 1 ARE CONSIDERED IN THE ANALYSES.

Scenario	Scums	MY FY	MY FN	MY ND	MN FY	MN FN	MN ND	Correct	Incorrect	ND	% total correct	% scums correct
Existing model	33	**28**	19	24	5	**3**	1	**31**	24	25	**56%**	**85%**
20 % wind reduction	33	28	20	24	5	2	1	30	25	25	55%	85%

FIGURE 5.11 MODEL OUTPUT OF (A) SCUM APPEARANCE, (B) SCUM DISAPPEARANCE, (C) SCUM BIOMASS AT LOCATION 4 (NORTHERN SHORELINE) AND (D) SCUM BIOMASS AT LOCATION 5 (EASTERN SHORELINE) FOR SIMULATIONS IF THE EXISTING MODEL AND SCENARIO OF A 20% REDUCTION IN WIND SPEED, DELFTSE HOUT, 5 – 18 SEPTEMBER 2008

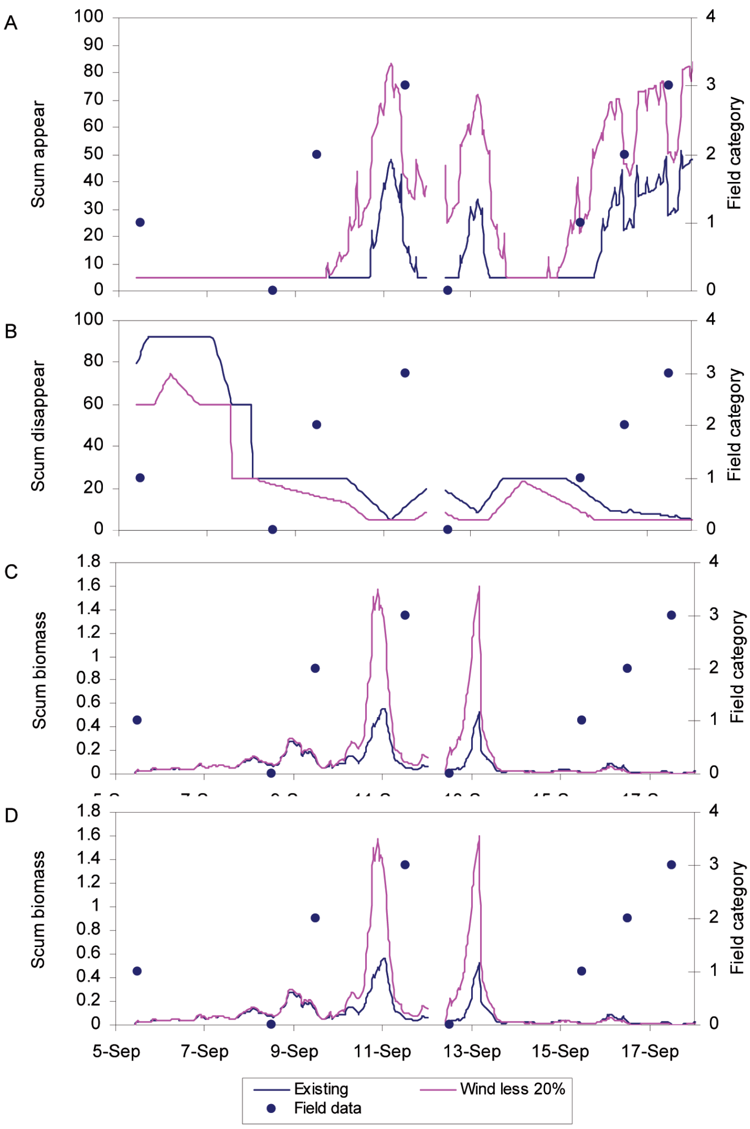
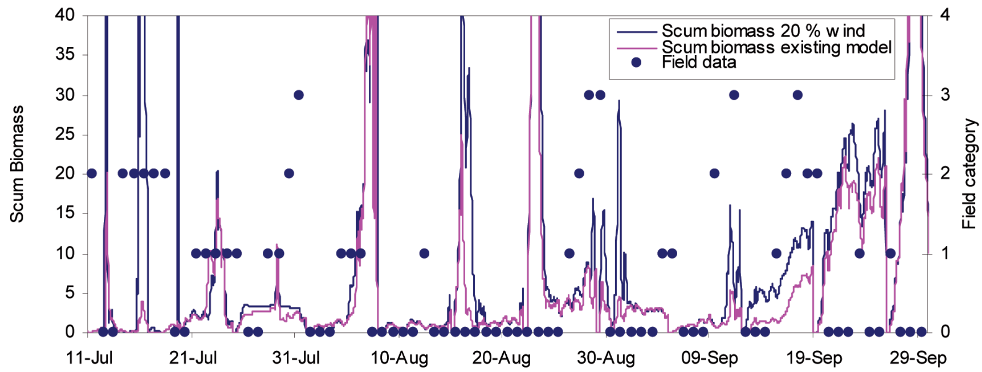


FIGURE 5.12 MODEL OUTPUT OF MAXIMUM SCUM BIOMASS ACROSS ALL AGGREGATED AREAS FOR SIMULATIONS IF THE EXISTING MODEL AND SCENARIO OF A 20% REDUCTION IN WIND SPEED, DELFTSE HOUT, 5 – 18 SEPTEMBER 2008



Due to the similarity between the results between the model runs with and without a 20% wind reduction, the wind reduction scenarios were not extended to the other three pilot lakes. Further scaling of the wind speed was also not considered to be important for further improvement of the model, and the changes were therefore also not implemented in the membership functions for wind speed appearance and disappearance.

5.3 ECOFUZZ STAND ALONE 2006

The EcoFuzz stand alone module was run hourly from 1 June to 30 September 2006 based on input of mean hourly wind speed and hourly total solar radiation derived from Schiphol Airport climate station. The results of model output for scum appearance were compared to all validation data available for the four pilot lakes, supplied by each Water Board.

For the Delftse Hout, the abundance of *Anabaena*, *Aphanizomenon*, *Microcystis* and *Planktothrix* were available on 10 days between May and September 2006, categorized into 5 classes ranging from low to very high abundance as well as surface scum presence. Over the 2006 summer period, cyanobacteria were nearly always observed in the lake, with very high concentrations or surface scums present on four of the ten samples available.

For the Sloterplas, the validation data available consisted of records of health warnings issued due to the presence of high cyanobacterial biomass. During summer 2006, two warnings were issued, lasting in duration from 3 (from 5 July) to 8 (from 24 July) days. Validation data available for the Westeinderplassen consisted of *Anabaena* and *Microcystis* abundance, categorized into 5 classes ranging from low to very high. High abundance was observed on two occasions in summer 2006. In addition, Microcystin concentrations were measured at a range of sites on seven occasions over the summer period, with concentrations exceeding 2 $\mu g\ L^{-1}$ somewhere in the lake on 4 days.

For Lakes Gooimeer and Eemmeer, validation data were only available based on expert judgement. Cyanobacterial scums over the 2006 summer period were suggested to be mostly present between the months of July and August as follows (Pers. Comm.):
- Persistent Category 3 scums along the shorelines of Lake Gooimeer
- Persistent Category 3 scums in Almere Harbour
- Persistent Category 1 scums in the centre of Lake Gooimeer
- Similar trends in the eastern and western regions of Lake Eemmeer

Cyanobacterial scums ranging from category 1 to 3 were also observed in Almere harbour in June and between August and the end of October 2006.

5.3.1 RESULTS

Model runs of scum appearance in summer 2006 suggested that cyanobacterial surface blooms would appear on 95 of the 122 days simulation period (Fig. 5.13). Over the period 14 July to 30 September 2006, there were 26% more scums present than in the same period in 2008 (Fig. 5.14).

In the Delftse Hout, where the available validation data coincided with 7 of the days simulated by the model, the field data supported the model predictions on all days (Fig. 5.15). In the Sloterplas, the model simulations predicted scum appearance for 8 of the 11 days on which a cyanobacterial health warning was issued, while in the Westeinderplassen the model predicted scum appearance on 3 of the 5 days for which data were available (Figs. 5.16 and 5.17).

Comparisons between the model prediction and validation data for Lakes Gooimeer and Eemmeer was more difficult as the days on which scums were suggested to be present in the field were based on expert knowledge rather than actual measurements.

FIGURE 5.13 SCUM APPEARANCE AND MEAN HOURLY WIND SPEED, 1 JUNE TO 30 SEPTEMBER 2006

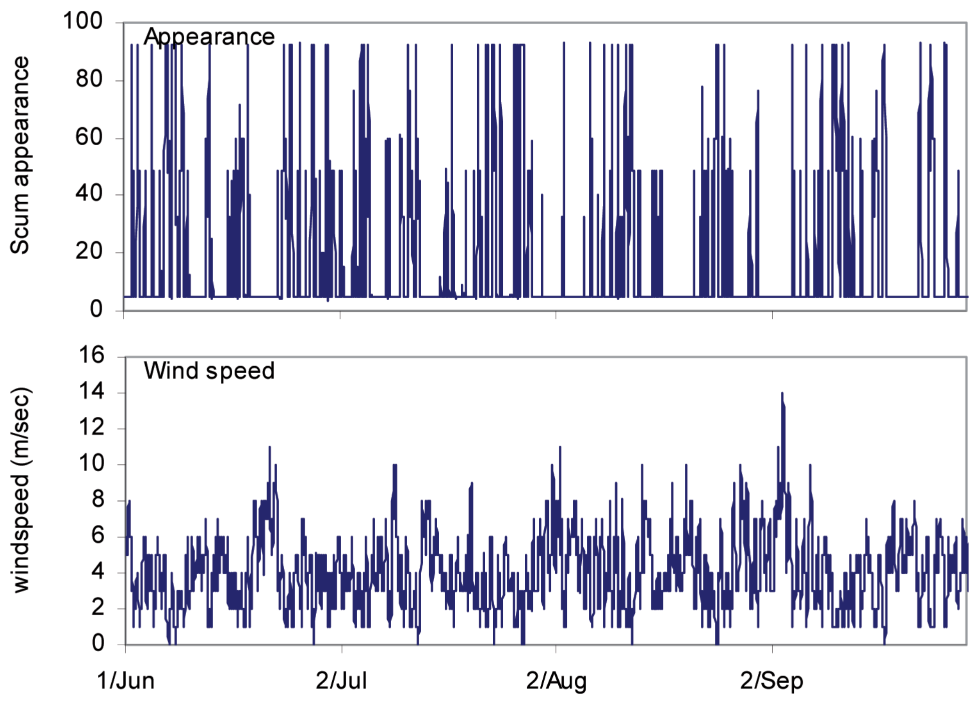


FIGURE 5.14 COMPARISONS BETWEEN MODEL OUTPUT OF SCUM APPEARANCE FOR SUMMER (14 JULY TO 30 SEPTEMBER) 2006 AND 2008

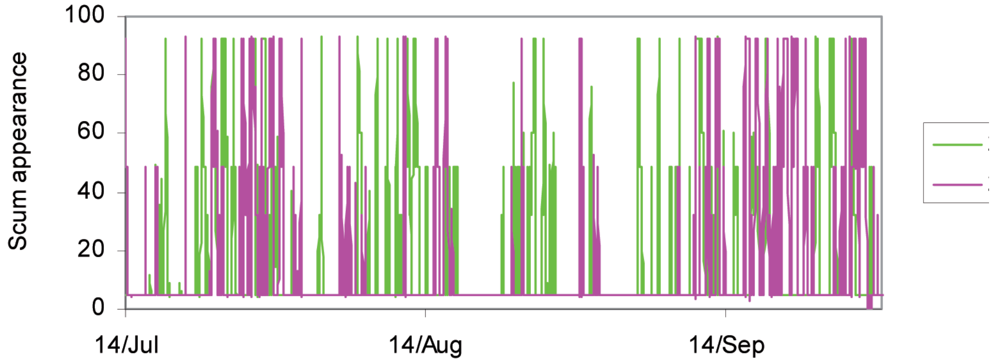


FIGURE 5.15 SCUM APPEARANCE AND AVAILABLE CYANOBACTERIA VALIDATION DATA FOR DELFTSE HOUT, 1 JUNE TO 30 SEPTEMBER, 2006. FOR THE VALIDATION DATA 'CYANO ABSENT' REPRESENTS NO OR VERY LOW WITH 'CYANO SCUMS' REPRESENTING SURFACE BLOOMS PRESENT ON THE LAKE

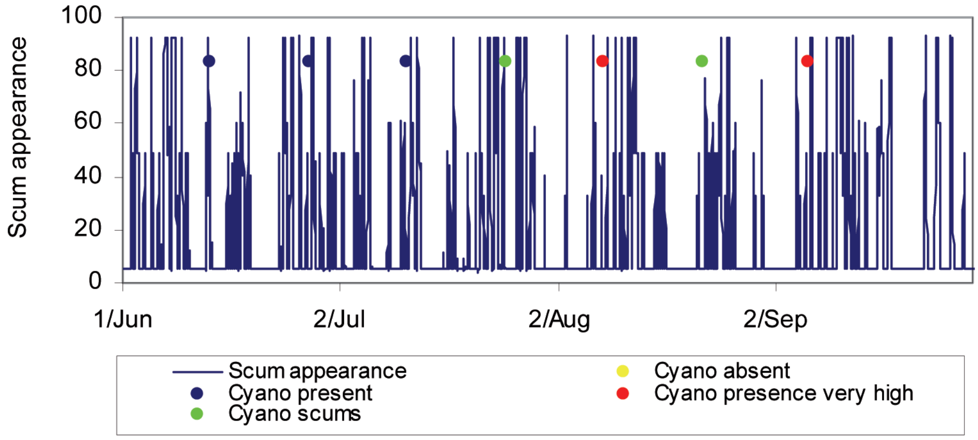


FIGURE 5.16 SCUM APPEARANCE AND AVAILABLE CYANOBACTERIA VALIDATION DATA FOR SLOTERPLAS, 1 JUNE TO 30 SEPTEMBER, 2006. FOR THE VALIDATION DATA 'CYANO WARNING' REPRESENTS DAYS ON WHICH ALGAL BLOOM WARNINGS WERE ISSUED TO RECREATIONAL USERS

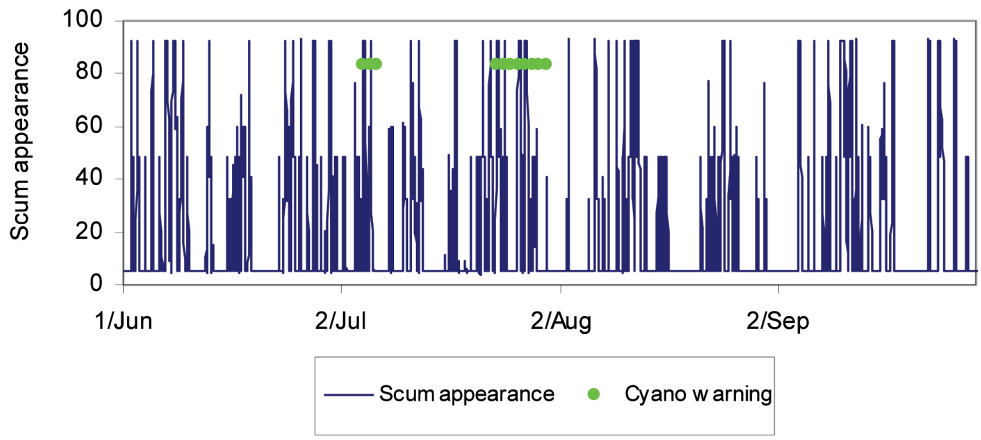
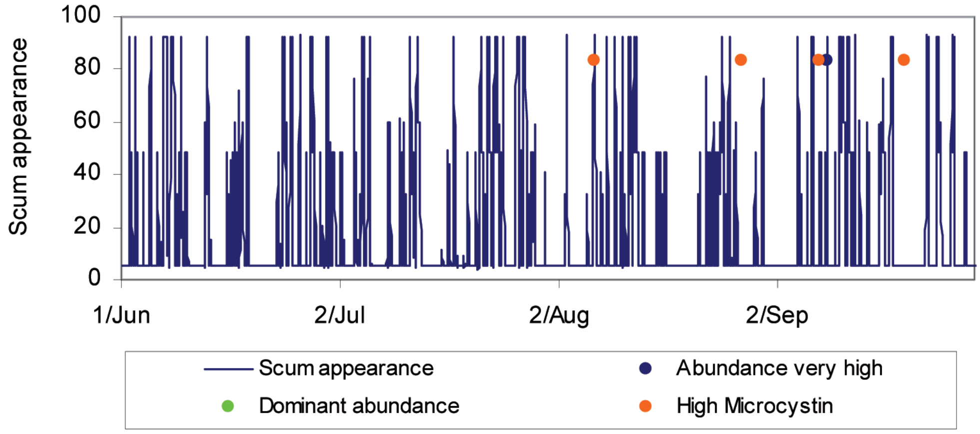


FIGURE 5.17 SCUM APPEARANCE AND AVAILABLE CYANOBACTERIA VALIDATION DATA FOR WESTEINDERPLASSEN, 1 JUNE TO 30 SEPTEMBER, 2006. FOR THE VALIDATION DATA, 'HIGH MICROCYSTIN' REPRESENTS DAYS ON WHICH MEASURED MICROCYSTIN CONCENTRATIONS EXCEEDED 2 UG L^{-1}



6

CONCLUSIONS

6.1 OPERATIONAL TESTING OF MODEL

The testing of the complete model instrumentation in an early warning context was beneficial to test the cooperation between the water boards, field sampling personal, lab analysis team and modelling staff required to delivery a forecast bulletin on time, as well as to highlight the potential factors which could limit the use of the model to deliver warning bulletins in sufficient time to be of use to the water managers. This part of the study has identified a number of points which should be further considered should the complete system become operational as a routine early warning system. These points are focused on delays with the water quality data delivery, and the format of the data being delivered.

6.1.1 WATER QUALITY INPUT DATA

Although the amount of data required to setup and run the model is not extensive compared to many water quality models, the parameters which are required to run the model are labour intensive in terms of sample collection and analysis. Phytoplankton biovolume measurements are only determined by external agencies, and the delays between sample collection and cell count determination can be high. There are typically many different individuals and organisations involved in the field sampling program to collect the phytoplankton samples and analyse for cell counts, and the summer cyanobacterial season coincides with the vacation period making planning between the different teams more difficult. The most cases of failed bulletin production were due to delays in the delivery of phytoplankton cell counts and chlorophyll-a concentration data, and as phytoplankton biomass is not simulated by the model, these parameters are essential to initialise the model.

A number of steps could be further considered to reduce the dependence on phytoplankton biovolume data, for example the use of fluoroprobes alone, but these are dependent on good calibration techniques. This is discussed further in the recommendations.

6.1.2 DATA FORMATTING

A number of steps are required to translate the provided raw data to the format required as input to both the hydrodynamic and water quality models. While in this study problems with the incorrect data format did not prevent the successful delivery of the bulletins, much time was spent on revising and reformatting data sets which at times changed from week to week. This included for example:

- changes in the raw data sequence;
- changes in the data format, for example numerical or as text,
- missing data.

In this study the reformatting of the raw data files was automated as much as possible through the use of a series of Excel templates for each lake, however, these did not work if the data changed in format or was absent. Should the system be even more automated, for example as is currently used for the Deltares North Sea FEWS Algal model, where meteorological data and water quality files are automatically imputed to the model from FTP servers, the correct data format each week is essential for the successful running of the system.

Setup of the current study into a FEWS type system would not have worked in the current study due to the many problems with data formats and trouble shooting.

6.2 EXISTING MODEL PERFORMANCE

Overall the model results compared weakly to the available field validation data for all lakes except for the Gooimeer and Eemmeer, where scores were high but the field validation data were very limited. Re-simulation of all model periods using observed rather than forecasted meteorological data did not lead to a large improvement in the mismatch between field and model output observed. A high number of false positive events were recorded in the Delftse Hout, Sloterplas and Westeinderplassen, mainly due to high scum appearance values, a phenomenon which was also observed in the 2007 study.

A detailed analysis of the Delftse Hout suggested that the false negative events are predominantly due to the high wind speeds at the moment that the field validation data suggests that a scum was present in the system. In the model simulations, a high wind speed generates a low scum appearance value and high scum disappearance value, with the end result being scum absence. In the Delftse Hout the large number of false positive events forecasted by the model were due to a combination of factors, the most important being low wind speed, and therefore high scum appearance output, and a delay in scum disappearance. For example the scum was often already declining but still present in the model, while already absent in the field validation data.

Various scoring methods were applied to try and improve the overall model score, and to better compare the model output of cyanobacterial scum concentrations with the field validation data consisting of scum categories. In general using a low model biomass threshold gave better results for the total model score overall, while maintaining a high score for total scum events although at the cost of a high number of false positive events. Both scores were generally better when only field scum categories of 2 or greater were applied.

Due to large mismatch between model scores and the field data, a comparison of model output for scum spatial distribution relative to the spatial distribution of the validation data was not considered feasible without further improvements in the model processes or setup.

6.3 REVISED MODEL PERFORMANCE

Based on the weak performance of the existing model, a number of further developments on the model framework through refinement of the processes for scum appearance and disappearance in the model code were conducted to try and improve the forecast scores. In addition, a number of variations in model data input formats were tested to try and reduce the high variations observed in the data (e.g. wind speed), and EcoFuzz stand alone model was applied for 2006 to test model performance in a year in which cyanobacteria scums were considered to be more problematic than in recent years.

The results of the revised modelling approaches tested suggest that at least for the Delftse Hout, the model is in a good state to predict the timing of cyanobacterial scums that are present in the system, with an accuracy of 85% relative to the field data for category 1 scums or more. This lake also represents the site with the most field data available for model calibration and validation, and further the data are highly reliable as all shorelines were assessed daily by the same team of people, and therefore although the field category scores remain subjective they are likely to have the same error rate over the whole period.

The revised modelling approach with grid cell specific scum appearance and disappearance routines led to an overall improvement in the total number of category 1 scums or greater forecasted, with little change in the overall model score relative to the previous model simulations.

The model also performed well for the timing of cyanobacterial scums for the Gooimeer and Eemmeer on the days for which validation data was available, although the total number of validation sampling days was low and more data are required to assess the model in this system more fully. In the Westeinderplassen model performance scored around 50% for both total model correct and total scums correct, while for the Sloterplas model performance could be considered poor due to the very low biomass forecasted.

Scores of model performance for the combination of accurate timing and scum location were less accurate than scores for only the timing of events, although the model is reset weekly based on limited biomass measurements for all systems while in the Delftse Hout, the number of zones used for the model output and validation data is perhaps too fine for such a small system. For the Gooimeer, Eemmeer and Westeinderplassen, the large number of zones used to aggregate the model results may also have been too small given the large size of the lakes and the limited validation data available to be able to assess the horizontal transport of scums accurately.

The results of variations in model light and wind speed input were marginal or had no effect on the existing model accuracy, and should therefore not be further applied to the final model instrumentation.

The results of the model simulations for scum appearance using EcoFuzz stand alone suggested that there were more cyanobacterial scums in summer 2006 then in 2008, which coincides with the general field knowledge that scums were more frequent and persistent over the 2006 summer period. The model results suggest that scum appearance was high and sustained throughout the summer period, although due to the differences in sampling frequency and programs between the four test lakes, it is difficult to compare the timing of large scum events between the four systems. Many scums were predicted accurately by the model relative to the available field data, however, the validation data was mostly collected only during scum events and false positive forecasts are therefore low.

6.4 MODEL PERFORMANCE AS AN EARLY WARNING SYSTEM

While the initial expectations of model performance by the water boards were desired to be very high (> 90%) for total model accuracy, these expectations were unjustified given the large number of uncertainties in the model input data, modelling approach, and model validation possibilities. In the Delftse Hout, which represented the system with the best model scores, the amount of false positive events predicted still remain high, although the current model results possibly represents the best scenario possible following much testing in both the previous and current study. While the primary goal of an early warning system should be to provide a timely forecast of cyanobacterial scum events and the secondary goal to reduce the number of false positive forecasts as much as possible, the use of the model even with false positive events is still suggested to offer a greater degree of accuracy in providing adequate warning against cyanobacterial scums to recreational users than the protocols currently applied by lake managers. In the absence of any models, cyanobacterial warnings are currently based only on weekly or even fortnightly samples which take time to process, and often lead to the delayed closure of a lake for up to weeks at a time during persistent scum years even when scums are absent for many of these days.

The 2008 summer did not represent a “good” year for cyanobacterial scums due to highly unstable weather patterns and limited periods of warm, calm, low wind conditions compared to more intense summers such as 2006. Model results of EcoFuzz stand alone demonstrated that the model was able to differentiate between good and bad cyanobacterial years, with more scums forecasted for 2006 than in 2008. Overall model performance of the complete instrument is therefore also likely to be much higher in persistent scum years than perhaps the low scum years observed throughout the duration of the current study.

The success of the complete early warning system is not based only on the performance of the modelling tool, but also on the regular collection of high quality field data for model input and validation. In this study the calibration and validation of the model results is based solely on validation data which is largely subjective and limited in space and time depending on the system. For example in the Gooimeer and Eemmeer, validation data collected by aeroplane and boat sampling on the same day and time step gave different results on many occasions. Also in the Sloterplas, where a large number of category 2 scum events were observed compared to all other systems, different scores were cited by different people in adjacent locations where the same scum was suggested to persist.

This highlights the complexity associated with collecting validation data when the method is based purely on subjective categories rather than quantitative data. Further, as cyanobacterial scums can appear and disappear on relatively short time scales, many events are likely to have been missed at the sampling frequency available for the study lakes. Therefore the observations are by definition biased, and model output of false positive events may actually be correct but cannot be fully validated.

The scoring of the model is also based on a number of steps used to compare the model qualitative data on an hourly time step with a high spatial cover with the more subjective field data collected at the very least on only one time step each day and not always for all shorelines across the whole system. The model calculates scum biomass for every grid cell, and spatial aggregation was applied to better compare the model output with actual shorelines of recreational beaches in the field. The area of the model zones over which the data was averaged may be too large for some systems, leading to a low scum biomass, while for the smaller systems such as the Delftse Hout the total number of zones examined may be at the limit of the model capabilities.

Finally, in the absence of modelling the phytoplankton biomass, the model is reset weekly based on the available weekly or fortnightly field data for a limited number of locations in each lake system. The presence of cyanobacterial scums and biomass is known to show very large spatial variations in the natural system, and although the model is reset as best as possible, the model restarts are not likely to capture all the natural variability each week and scum forecasts may therefore be affected. The model resets are also based on standard conversions between chlorophyll-a concentration and carbon biomass (chl-a:C ratio 40), which are known to vary depending on lake trophic status. The actual measurement of these ratios for each system as well as quantification of the carbon biomass which approximates to each of the field scum categories may also improve the modelling approach and comparisons between field data and model output.

6.5 RECOMMENDATIONS

The model in its present form is suggested to be in a good state to forecast the timing of surface scums at least for the Delftse Hout, but at the limit of what can be achieved with the current combination of fuzzy logic with deterministic modelling and the weekly phytoplankton biomass resets. Furthermore, although much effort has gone into collecting the validation data, more quantitative field data at an even higher frequency would further benefit model collaboration allowing for true comparisons of field and model data. Further developments are also required to better understand the process of scum development.

Based on the results of the present study we make the following recommendations:

1 **Validation data**:
- ○ Focus on the collection of quantitative rather than subjective field validation data at high temporal and spatial resolution to further enhance the calibration process;
  - the use of automated shore or buoy mounted high definition spectral cameras to quantify cyanobacterial biomass and spatial distribution at finer time scales;
  - the use of webcams to monitor scum location;
  - provide better instruction to volunteers collecting the field validation data to improve the quality of the data collected, including organising a presentation on the EWACS program and creating a more detailed instruction manual.
  - quantification of approximate scum biomass as carbon biomass associated with the current field categories 1 to 3 allow better comparisons between model output and field data.

2. **Modelling approach:**
- ○ Deterministic modelling of scum appearance and disappearance:
  - Comparative study of current fuzzy logic approach and deterministic modelling based on phytoplankton resets with a full deterministic approach in which phytoplankton biomass and water column nutrients are fully simulated in combination with the fuzzy logic model for scum formation (for instance at lake IJsselmeer, where both models currently exist);
  - Further testing of a deterministic approach which excludes the fuzzy logic component and instead simulates scum appearance and disappearance through new processes coupled to flow velocities, for example through eddy diffusivity output from the hydrodynamic model;
  - Further development of a Delft FEWS type system where the complete model instrumentation is fully automated, including data setup and input, model runs and bulletin production.
  - refinement of the model grid along lake shorelines;
- ○ Continuous modelling rather than weekly resets to reduce errors associated with model resets and distortion of spatial scum trends.

7

LITERATURE

Deltares, 2008: EWACS (Early Warning Against sCumS) Phase 1 research report. Authors D.F. Burger, R.P. Hulsbergen, F.J. Los and S. Groot. Delft 112 pp.

Ibelings, Bas W., Marijke Vonk, Hans F.J. Los, Diederik van der Molen and Wolf M. Mooij, 2003. Fuzzy modelling of cyanobacterial surface water blooms: validation with NOAA-AVHRR satellite images. Ecological Applications, 13(5) 1456-1472.

Los, F.J., 1991. Mathematical Simulation of Algae Blooms by the Model BLOOM-II Version 2. WL | Delft Hydraulics, Delft T68.

WL | Delft Hydraulics, 2005. Technical Reference Manual Delft3D-WAQ. 397 pp.

APPENDICES

CYANOBACTERIA WORKSHOP

Verslag EWACS Workshop Blauwalgen Drijflagen
9 september 2008 - Utrecht

Deelnemers:	Jutta Passarge	
	Delfland	
	Petra Visser	*UvA*
	Edwin Kardinaal	*DHV* (tot 11:15 uur)
	Jacco Kromkamp	*NIOO*
	Miguel Dionisio Pires	*Deltares*
	Jasper Stroom	*Waternet* / voorzitter BegeleidingsCommissie
	Imke Leenen	*Rijnland en Grontmij* / BegeleidingsCommissie
	Wolf Mooij	*NIOO* / BegeleidingsCommissie
	Johan Oosterbaan	*Delfland* / BegeleidingsCommissie
	Simon Groot	*Deltares* / projectteamleider
	David Burger	*Deltares* / projectteam
	Bas Ibelings	*EAWAG* / projectteam

Programma:

9.30 – 9.40	Doelstelling en achtergronden EWACS project *(Jasper Stroom)*
9.40 – 10.00	Introductie dynamiek van cyano-drijflagen en fuzzy logic modellering *(Bas Ibelings)*
10.00 – 10.15	Kort overzicht EWACS-modelopzet (huidige studie) *(David Burger)*
10.30 – 11.45	Discussie over de mechanismen van drijflaagvorming van cyano's

Verslag:

Doelstelling en achtergronden EWACS project
Jasper Stroom schetst de achtergronden van het EWACS project en de belangrijkste vragen en doelstellingen van de activiteiten in 2007 en 2008. Belangrijkste is om te voldoen aan de zwemwaterrichtlijn door tijdig maatregelen te kunnen inzetten. Maatregelen kunnen werkelijke beheersmaatregelen zijn (pompen e.d.), maar ook tijdig waarschuwen is van belang om te voldoen. Korte discussie over de problemen die optreden in de situatie met drijflagen. Er is weinig bekend over de gezondheidseffecten van blauwalgendrijflagen in Nederland, waarschijnlijk mede omdat de gezondheidseffecten moeilijk te onderscheiden zijn van andere ziektes en allergieën. Er zijn weinig echte probleemgevallen bekend, ook al omdat er vaak voor die tijd al een zwemverbod wordt ingesteld of andere maatregelen worden genomen. Er zijn bij de aanwezigen 3 publicaties bekend waarin de aan drijflagen en toxines gerelateerde problemen op de menselijke gezondheid worden beschreven.

Introductie dynamiek van cyano-drijflagen en fuzzy logic modellering
Bas Ibelings schetst de beschrijving van drijflagen met behulp van fuzzy logic, met toepassingen op het IJsselmeer en de momenteel via EWACS op een viertal pilot-gebieden. Drijflagen kunnen optreden als wordt voldaan aan drie condities: voldoende biomassa, voldoende stabiliteit van de waterkolom, en voldoende drijfvermogen van de algensoorten.

Fuzzy logic kan beter omgaan met de praktijk van incomplete kennis en onzeker relaties, en sluit meer aan bij een intuïtieve manier van beslissen en handelen. Fuzzy logic maakt geen gebruik van statistiek of stochastiek. In de eerste stap vindt er 'fuzzy-fication' plaats en wordt de beschikbare expert-kennis in kennisregels vertaald. Vervolgens worden er 'if-then' regels opgesteld ('fuzzy-inference'), gevolgd door een 'de-fuzzyfication' waarin een terugvertaling naar kwantificeerde variabelen plaatsvindt. Jacco merkt op dat in het fuzzy IJsselmeermodel dus geen stijgsnelheden zijn opgenomen. Daarnaast zit in de fuzzy regels geen foto-inhibitie.

In het instrument wordt nu alleen de instraling boven de waterkolom gebruikt en niet de beschikbare hoeveelheid licht IN de waterkolom.

Bas merkt op dat het drijfvermogen (buoyancy) hoog is in de ochtend en gering is in de middag (suikerproductie). Petra geeft aan dat bij laboratoriumproeven met weinig nutriënten vaak samengaat met weinig drijfvermogen. Bij snelle groei lijkt de aanmaak van gasvacuolen achter te blijven, waardoor cyano's minder zullen drijven. Ook bij weinig licht is dit het geval en dat spoort met ervaringen in het veld. Na een periode van weinig licht is er meer kans op drijflagen. Het kan ook zijn dat tijdens de groei gasvacuolen klappen. Dit soort zaken werken op verschillende tijdschalen. Van tijdschalen op uurbasis tot een historie van meerdere dagen.

Vooral licht is een lastige parameter. Het gaat niet alleen om de totale hoeveelheid licht, maar ook om de intensiteit. Kortdurend veel licht levert niet hetzelfde als langduriger minder licht (bij dezelfde totale hoeveelheid licht).

Edwin vraagt zich af hoe erg het is dat drijflagen soms onterecht worden voorspeld ('false positives'). Jutta stelt dat er niet te lang onnodig zwemverboden moeten komen, dus het aantal 'false positives' moet laag zijn. Jasper geeft aan dat deze discussie relevant wordt in een later stadium, namelijk als we EWACS operationeel willen maken. We zitten nu in de fase dat we het simpelweg zo goed mogelijk willen doen, en dus willen kijken hoe goed we de werkelijkheid kunnen benaderen. Deze discussie raakt aan een latere opmerking van David over wat de definitie is van een drijflaag en wat er nu eigenlijk van belang is voor de waterbeheerder.

Kort overzicht EWACS-modelopzet

David Burger presenteert de modelopzet en de ervaringen met het model in de zomers van 2007 en 2008. In de zomer van 2007 zijn geen langdurige drijflagen waargenomen (slechts 13 gebeurtenissen van meestal 1 dag). In 2008 was er voldoende biomassa, maar waarschijnlijk vanwege de geringe stabiliteit van de waterkolom geen grote problemen met drijflagen. Bij de waarnemingen is een indeling van drijflagen in 4 categorieën gebruikt in 2007. In 2008 worden 3 categorieën gebruikt.

Jacco geeft aan dat persistente drijflagen niet vaak voorkomen: omdat drijflagen vooral in de ochtend optreden hoeft het model (rond 13:00 uur) niet fout te zijn.

Petra vraagt of de algen in het model niet teveel drijven: bij gunstige omstandigheden wordt alle biomassa in de bovenste laag verondersteld, terwijl dat in de praktijk afhangt van de stijgsnelheden en van de kolonie-grootte. Daarna ontstaat er discussie over de omstandigheden in een drijflaag, gevolgd door de conclusie dat de koloniegrootte niet wordt beschouwd in de kennisregels, maar dat die in de praktijk wel heel belangrijk is voor de stijg- en daalsnelheden. Jacco vraagt zich af hoe we in het model om kunnen gaan met de hoge lichtintensiteit aan het wateroppervlak (toplaag). Wellicht is het beter om uit te gaan van het lichtniveau IN de waterkolom. Volgens David blijft calibratie van dit soort processen op basis van de huidige meetgegevens lastig.

Na een discussie over de fuzzy regels en windinvloeden merkt Simon op dat de beschutting (strijklengte) niet doorwerkt in de fuzzy regels, maar wel in de berekeningen van de waterbeweging via Delft3D. Optie is om de strijklengte ook te verdisconteren in de fuzzy regels (stabiliteit van de waterkolom). Strijklengte dus meenemen als kennisregel. Jasper suggereert te koppelen aan de info van het flow-model (Gis-file?), waarin strijklengte afhankelijk van de windrichting een windfetch factor meekrijgt.

Jacco adviseert om rekening te houden met het licht in de voorafgaande 6 uren, al komt een categorie 3 drijflaag pas na een veel langere periode tot ontwikkeling. Dus een nieuwe fuzzy-regel die de lichthistorie van de afgelopen 3 dagen beschouwt? De lichtgeschiedenis is van belang, maar is ook lastig te modelleren (het dag/nacht ritme en de verschillen in intensiteit). Volgens Jutta kunnen een aantal kennisregels worden afgeleid uit een goed fysiologisch model. Jutta heeft een dergelijk model (in PASCAL) operationeel waarin stijgsnelheden op basis van de aanmaak van koolhydraten versus gasvacuolen worden berekend (biomassa en kolonie-groei). In het lab is er zonder wind altijd een drijflaag. Momenteel wordt gewerkt aan de publicatie van de resultaten (eind 2008?).

Het opleggen van de (gemeten) biomassa in plaats van die met een model te berekenen wordt algemeen onderschreven. Er is nog wel discussie over welke soorten voor drijflagen kunnen zorgen en van welke soorten de biomassa in de fuzzy regels moet worden meegenomen (*Anabaena*, *Aphanizomenon*, *Microcystis*, *Gloeotrichia*). Petra checkt nog de toxine productie door *Aphanizomenon*.

Wolf vindt dat er een betere doelfunctie moet worden geformuleerd – daarvoor is nu nog geen formele procedure opgesteld. Pas daarna kunnen we beoordelen hoe goed de fit is.

Aanwezigen onderschrijven de stelling om voorlopig door te gaan met een op fuzzy logic gebaseerde model-aanpak in plaats van met de gebruikelijke deterministische beschrijving.

Conclusies:

Belangrijkste bevindingen en aanbevelingen van de workshop

1. Voeg het lichtniveau IN de waterkolom toe aan de lidmaatschapsfuncties in EcoFuzz. Op dit moment beschouwt het model het licht aan het wateroppervlak.
2. Langere termijn lichtgeschiedenis toevoegen.
3. Gebruik EcoFuzz om in iedere gridcel de drijflaag-potentie te kwantificeren en houdt daarbij rekening met de al aanwezige drijflagen en een verminderd lichtniveau. Kan eventueel als een aparte/extra rekenregel worden ingevoerd.
4. Strijklengte moet worden toegevoegd aan de lidmaatschapsfuncties.
5. Definieer een nieuwe lidmaatschapsfunctie om persistente (meerdaagse) drijflagen te beschrijven.
6. Drijflagen komen vooral in de ochtend voor. Probleem is dat zwakke drijflagen snel weer verdwijnen en niet kunnen worden gevalideerd met metingen om 13:00 uur. Oplossing kan zijn om ochtend-drijflagen te valideren.

7. De lidmaatschapsfuncties voor het ontstaan van drijflagen lijken te simplistisch. Zo is bijvoorbeeld de kolonie-grootte niet verdisconteerd (bijvoorbeeld Microcystis), wat belangrijk kan zijn voor het drijfvermogen (afhankelijk van kolonie-grootte).
8. Mesocosms experimenten kunnen een beter zicht geven op modelresultaten en validatie gegevens uit het veld. Bijvoorbeeld de vraag welke biomassa in het veld hoort bij een categorie 2 drijflaag.
9. De modelaanpak is goed, want als er meer fysiologische condities in het model worden opgenomen kan het geheel te complex worden in het gebruik en worden de resultaten mogelijk minder betrouwbaar.
10. Toxines zijn niet meegenomen in het modelconcept. Deze aanpak lijkt gerechtvaardigd omdat zwemverboden meestal worden gebaseerd op celtellingen van cyanobacteriën en niet op basis van toxine concentraties. Om die reden is ook de beschouwing van andere (mogelijk meer toxische) algensoorten zoals *Cylindrospermopsis* niet relevant.
11. Er moet een formele validatie-methode en doelfunctie worden vastgesteld waarmee de kracht van het model kan worden geanalyseerd met behulp van de verkregen meetgegevens.
12. Het is nog niet duidelijk waarom het model niet goed scoort in de ‘false positive’ situaties.

STICHTING
TOEGEPAST ONDERZOEK WATERBEHEER

stowa@stowa.nl www.stowa.nl
TEL 030 232 11 99 FAX 030 232 17 66
Arthur van Schendelstraat 816
POSTBUS 8090 3503 RB UTRECHT