Use of Remote Sensing Techniques in Modelling the Tiber River Plume.

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Abstract. A research programme has been carrying on to determine whether local sea and beaches pollution is attributable to the Tiber River.This paper describes part of this work,i.e. how aerial infrared images and in situ measurements can be used to study the fresh water physical dispersion,and in particular to develop a 1-D integral mathematical model for the buoyant surface plume.

Résumé. L'étude de l'effet du décharge du fleuve Tibre dans la zone côtière sur la pollution des eaux néritiques et des plages est en cours. Dans cette recherche on utilise la teledetection aérienne infrarouge et des observations in situ pour étudier en particulier la dispersion physique et pour bâtir un model integral 1-D mathematique de la distribution de la nappe d'eau douce.

Introduction. The worst conditions as regards pollution of the beaches probably occour during steady onshore breezes, which would drag the surface layers of the polluted plume towards the coast whithout breaking them up. Therefore we began studying steady state conditions.

Aims. To simulate the distribution of salinity and temperature (and pollutants) in the plume; also to obtain some measure of the velocity field.

Main feature. The prediction of temperature field is compared to infrared aerial images (9-11 micron band) (1) to calibrate the 1-D mathematical model.

Warning note. The (steady) 1-D model can be used for variations in discharge,ambient velocity,etc. which occour slowly! Therefore the steady model is no longer valid when stronger winds generate a choppy sea with breaking waves which will rapidly mix the thin surface plume layer with the "clean" sea water below.

Procedure. The governing equations are integrated across the plume in sections perpendicular to the x-axis (y-z-sections) The variations of temperature,salinity and velocity in a y-z-section is assumed to have a form,

$$\delta t(x,y,z) = \delta t_m(x) f(y/b) g(z/h)$$

where $t_m(x)$ refers to the plume centerline, b is the plume width and h is the depth; f(y/b) and g(z/h) are obtained by comparison with aerial infrared data (for f) and in situ vertical profiles (for g). We then assume that there is negligible heat loss to the atmosphere (measurements are taken when fresh water is colder than salt water) and that the temperature and salinity fields are the same. Inspection of data suggest a gaussian profile in the y-direction and a linear or gaussian profile in the z-direction. Basic difficulty. Theese profiles are not correct for the region extremely near the outfall. We have not decided how to handle this region but it may be best to use the data to evaluate the dilution. The model will then be applied from some distance from the discharge.

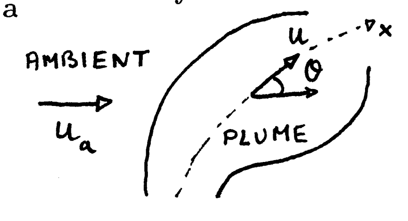
The conservation of water. If u is the velocity in the direction of the plume axis then the plume discharge is $\int udA$. The discharge variation represents the rate of entrainment of sea water, so

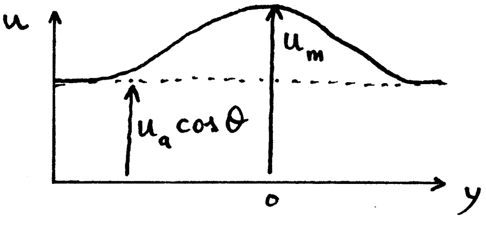
$$\frac{d}{dx}\int udA = \text{entrainment/unit lenght.}$$

Entrainment is usually expressed as vertical + lateral. The lateral is decreased as the depth/width ratio $> 10^3$. The vertical entrainment is decreased due to the stratification. For example:

$$\text{entrainment/unit lenght} = \alpha u_m + \beta e^{-kRi} b,$$

where Ri is the Richardson number, α and β are entrainment parameters and k represents vertical suppression. Harleman (2) has K=5. The two parameters α and β still depend on u_a=velocity of ambient water. Here,





$$u - u_a\cos\theta = u_m(x) f(y/b) g(z/h).$$

The conservation of salt. It is assumed that the salt and temperature differences decrease only due to dilution. The turbulent diffusivities are supposed the same so that the y and z profiles are the same. We then assume that the salt flux through A is $\int usdA$. This will increase with entrainment so that: change in $\int u\, s\, dA$ = change in $\int u\, dA\, s_a$. This means that $\int u(s_a - s)dA$ = constant, i.e. the flux of buoyancy $\delta\rho$ is constant.

The equation of plume width. Several formulae for b have been suggested. Harleman uses one which predicts $\frac{d^2b}{dx^2} > 0$ so that the plume shape is

(mainly turbulence)

However the Tiber plume looks more like $\frac{d^2b}{dx^2} < 0$ (1) with a shape (from aerial images)

(mainly buoyancy)

One formula which has been used derives from the rate of advance of a density current

$$u = \sqrt{\delta\rho/\rho_a\, gh} \quad \text{with } a = \text{constant.}$$

If u is the sideways velocity of the plume this suggest

$$u_m \frac{db}{dx} = a \sqrt{gh \frac{(\delta\rho)_m}{\rho_a}} \quad \text{where } a = \text{constant} \simeq 1.$$

We define

$$u_m / \sqrt{gh \frac{(\delta\rho)_m}{\rho_a}} = \text{Froude number (in this case} \simeq 1).$$

The momentum equation. If buoyancy were negligible then the momentum flux along the plume $\int u^2 dA$ is constant(apart from entrained momentum and wind effects). This would give $u_m \propto (\delta\rho)_m$ which is roughly correct in absence of wind. The effect of wind is to impose a stress proportional to $(u-u_{wind})^2$ in the direction of wind.

The buoyancy effect. Occours chiefly because of longitudinal density gradient in the plume. This causes a retardation but the effect may be small. The effect of a cross-flow is to bend the plume as it entrains fluid with a cross-plume momentum. As eddies form behind the plume, a simple drag force may be present.

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